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Full Length Research Paper

Energy consumption and expenditure of *Panthera pardus* in the Southern African region: How much hunting success is enough?

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***Panthera pardus* is a widespread mammalian carnivore, with a very broad diet range. Therefore, it is often seen as needing less protection as compared with some other predator species. However, with a 37% reduction in historic range and some subspecies critically endangered, the leopard is a species that does indeed require certain conservation attention. In Southern Africa, there are several threats facing the leopard: habitat loss, poaching, as well as killings associated with leopard-human conflict (the latter being aggravated by poorly-stocked reserves where the animals reside). In setting aside formal protected areas for the leopard and its prey, it is important to plan and stock these reserves in such a manner so as to limit potential conflict with owners of surrounding farmlands or tribal land. Focusing on the average daily energetic consumption and expenditure of the leopard in Southern Africa, this paper seeks to determine how regular successful hunts can help maintain the animal. It was found from the study that there is a very close balance between the energy consumption and expenditure of the leopard. Depopulation of a varying intensity may result from a hunting success probability below 0.5. Leopards are unlikely to persist where hunting success is reduced to 0.1 due to prey shortage. This finding is believed to provide some preliminary guidance for leopard prey stocking rates in the future.**

Key words: African leopard, energy expenditure, prey stocking rate, leopard-farmer conflict, conservation, predator-prey interaction.

INTRODUCTION

There are a wide suite of conservation issues in the modern age (Gurevitch and Padilla, 2004; Giam et al., 2010; Bellard et al., 2012), each having a variety of often negative implications on global biodiversity, and each demanding attention (Sheil, 2001), research, and funding to address (or at the very least, to attempt to do so). One of the biggest conservation concerns, and one that is very often implicated in extinctions of species in modern times, is habitat loss (Simberloff, 1984; Tilman et al., 1994). Habitat loss causes a reduction in population size,

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leaving a species more prone to the effects of stochastic events (Burkey, 1995), and thus increasing the potentiality of its extinction. The loss of habitat in general tends to outweigh the effects of fragmentation of such habitat (Fahrig, 1997), and is aggravated by land conversion tending to be non-random (Seabloom *et al*., 2002), biased towards areas valued agriculturally or those with a particular geographic placement.

Panthera pardus is classified as a vulnerable predatory species according to the latest IUCN Red List (Stein et al., 2016). It has a wide distribution comprising a broad region in Africa (with the Sahara Desert excluded from its range), the Arabian Peninsula, southwest Asia, as well as a small population maintained in the Russian Far-East (Nowell and Jackson, 1996). While some estimates show its Southern African range as being in no immediate danger of a severe decline (Martin and de Meulenaer, 1988), there have been criticisms of these estimates (Norton, 1990), as there are marked reductions in areas of encroaching human settlement and other habitat conversions, with range decline for the species being as high as 37% in a period of 100 years (Ray et al., 2005).

*P. p. pardus*is an African sub-species of the leopard, with some 78% of the overall species range occupied by this variant (Jacobson et al., 2016). South Africa is responsible for some of the biggest habitat losses for the species, with leopards in unprotected areas being severely restricted in their occurrence (Skead, 2007). One case of this was noted in the Phinda-Mkhuze Complex, a small region lying along the eastern edge of South Africa, where the observed number of leopards was on average 11.11/100 km^2 within the protected Mkhuze Game Reserve (core protected area), 7.17/100 km^2 in the neighbouring Phinda Private Game Reserve (buffer protected area), and then only 2.49/100 km^2 in the surrounding non-protected lands used for livestock farming, private game ranches and tribal land (Balme et al., 2010). With poaching and trophy hunting still being prominent factors driving leopard population in South Africa, there is an added potential risk of leopards being subjected to retaliatory farmer killings because of the real and perceived threats that these animals pose to livestock, as leopards tend to easily cross boundary fences (Balme et al., 2009; Chapman and Balme, 2010). Therefore, despite about 20% of South Africa currently providing suitable leopard habitat (Swanepoel et al., 2013), there is a need for a thorough investigation of the potential of the species to experience a further decline, as suggested by the decreasing population trend predicted by the IUCN (Stein et al., 2016).

An important factor to consider when determining the potentiality of a population decline is to examine the species' physiological needs against the resources that the environment in which the species occurs is actually capable of providing at any given time (Wikelski and Cooke, 2006). If the surrounding environment falls short of meeting an animal's physiological needs, the animal is faced with a decision to either relocate elsewhere in search of resources or to face death from starvation in its current habitat (Stephens, 2008). However, where threats such as poaching and legal hunting outside the habitat pose a life-threatening risk of their own (as earlier mentioned) – the surrounding matrix is in itself an unpredictable habitat – the animal may still face the same fate outside the poor habitat as it would by remaining there (Switzer, 1993). Therefore, using the physiological needs of species to determine the required energetic quality of the habitat to maintain a viable population is a useful technique in helping inform habitat management (particularly where such habitat is facing the potentiality of, for example, habitat loss (Fahrig, 2001)). When assessing the energetic needs of a predator, it is of fundamental importance to consider the interactions that they have with their potential prey – a relationship that is instrumental in regulating and shaping both populations and communities at large (Fretwell, 1987). Not only does the predator-prey relationship affect prey numbers as per predator kills, but extensive phenotypic changes can be induced in the prey as a response (Werner and Peacor, 2003), and prey intimidation has an effect on their demographics comparable to those resulting from prey consumption (Preisser et al., 2005).

In accounting for the predator-prey interaction that exists between leopards and their prey (mostly mammalian species with a weight range of 10 to 40 kg, as per Hayward et al., 2006), it is also important to consider the effects of spatial heterogeneity on modifying the functional response (Gorini et al., 2012). In a heterogeneous system that tends to persist in real-life scenarios, the leopard will face regular challenges not only in searching for and encountering prey, but also in actually killing and consuming it.

A factor complicating the matter even further in the modern times is human disruption: anthropogenic activities can directly influence the nature of the relationship between a predator and its prey, whether by controlling the numbers of the respective species, or by providing food subsidies (Rodewald et al., 2011). In the case of the leopard, subsidies may be provided accidentally, such as domestic livestock that the predator may take to hunting (Kissui, 2008). Being assisted by the natural tendency of leopards to roam widely in search of prey, the animals can easily become involved in tense human-animal interactions with the owners of private lands (as earlier mentioned). As such, in assisting the survival of the species, conservation efforts need to be adequately backed by knowledge of how much wild prey should be stocked in reserves, to allow leopard densities to stabilize in accordance with their main natural prey, as is common for predators (Karanth et al., 2004). This should also assist in reducing incidences of livestock killing. To determine this, a detailed analysis is needed of the difference between energetic consumption and expenditure of the animal, and how vulnerable it actually is to having its energy intake fall below its rate of utilization, upon which a steady decline in weight and activity levels ensues and the potential of death becomes a serious threat. This parameter is closely examined henceforth.

METHODOLOGY

An energetic model for *P. pardus* was constructed, using standard work (W) equations (presented in kilojoule (kJ) measurement units), which relates directly to kinetic energy according to the work-energy principle. Input values for the model were sourced from a variety of literature, obtaining specific values on feeding, hunting and other behaviours as is accurate for the species.

For the purposes of standardization, the *p. pardus* subspecies was chosen as the subject to allow for maximal consistency of the input values, given the well-defined genetic differences between the various subspecies (Miththapala et al., 1996). Where required energetic values were not available specifically for the African leopard, the closest approximation was chosen, that is, first looking for values concerning the leopard, followed by a search for felids at large, etc. The model environment selected for the subject to operate in was the savanna biome of Southern Africa, more specifically the northern Kwa-Zulu Natal (due to the concentration of leopard studies in that region), obtaining the physiologically relevant seasonal temperatures, the diurnal/nocturnal differences as appropriate for the region, as well as other atmospheric properties such as average wind speed, from literature sources.

Following this, a statistically-average African leopard was defined, to allow for the refinement of the energetic results obtained. An average daily energetic gain was determined for the leopard subject, using the values obtained for prey consumption. On the opposite end of the scales, the basal metabolic energy consumption of the subject was determined, followed by heat-related costs to the organism (such as due to radiation, convection, etc.). Lastly, energy costs associated with obtaining prey were calculated. Summing all the determined energetic costs and weighing those up against the average energetic gains the leopard can be expected to obtain, allowed the determination of the extent of the difference between the energy gains and losses. The energetic surplus would be used by the organism to meet other, non-daily, needs such as breeding effort or emigration out of an area (Parker et al., 2009).

The results of the model provide another important finding: an estimation of how many hunting attempts on average before success are possible to warrant an organism's continued survival. Using this value, various scenarios of catch probability were tested to determine how many hunting attempts were required before a catch was made under each case. Given that a higher prey density is strongly related to the incidence of a successful catch (Whitfield, 2003), catch probability served as a proxy for prey stocking rates in the environment tested. This allowed for the determination of the lowest hunting success probability (that is, prey stocking rates) at which the leopard would still be able to obtain a hunt before the average number of hunting attempts, as allowed by standard daily energy reserves, were exhausted.

RESULTS

One of the main factors involved in energy expenditure, is that required for the correct functioning of internal organs such as the heart, the lungs, liver, etc. Even while being within a state of relative physical inactivity, there is a continuous utilization of energy for the continuation of basal metabolism, characterized by catabolism of compounds with oxygen intake.

The rate of oxygen consumption by the animal, the energetic output produced, as well as the rate of carbon dioxide release, is interrelated. If carbohydrates are subjected to oxidation, the intake of one litre of oxygen frees up 21.13 kJ of energy. If there is a similar oxidation of proteins and lipids, then 19.66 and 20.08 kJ of energy are released, respectively. For an adult animal on average, the hourly basal metabolism uses up 4.2 kJ for a kilogram of body weight.

Energetic balance analysis defines the following parameters for an adult leopard of mean statistical parameters in Southern African savanna: a body mass of 60 kg and a body surface area of 1.53 m^2 (using Meeh coefficient of 10 for an average cat, given by Schmidt-Nielsen, 1984).

P. pardus has an internal body temperature of about 39.86°C (Deka et al., 2012), while the ambient temperature in its savanna habitat fluctuates seasonally (Balme et al., 2007). Midday temperatures range from 23°C in July to 30°C in January (BirdLife South Africa, 2016), while night-time temperatures of 11°C in July and 20°C in January. Averaging, we obtain: 26.5°C in summer and 15.5°C in winter. The dermal layers of an animal tend to be a few degrees cooler than the rectal temperatures as recorded by Deka et al. (2012), with the epidermis being where internal and ambient temperatures meet (ambient temperatures averaging about 26°C in Southern African savanna). Given the aforementioned considerations, this study assumes an average epidermal temperature to be about 30°C for the African leopard (*p. pardus*).

Further, the study assumes that a statistically-average African leopard in African savanna has a daily meat consumption of 3.25 kg, since this is the median value of a leopard's 1.6-4.9 kg meat/day consumption recorded in the literature (Bothma and Le Riche, 1986; Bailey, 1993; Stander et al., 1997). African leopards are known to strongly prefer killing impala and bushbuck, with an average body mass of 23 kg (Hayward et al., 2006). The energetic content of this game can be estimated at 8.5 kJ/g, since venison is considered to be a much leaner type of meat than that of cattle, with a common fat content being less than 3% (Schönfeldt, 1993; Hoffman, 2000). The quantity of energy obtained by an African leopard in a single statistically-average 24-h period therefore becomes:

$$W_{EO} = 8.5kJ*(1000*3.25kg) = 27625 \text{ kJ}.$$

Utilization of the energy source provides for sustenance of a leopard's life until the next successful hunt. Loss of energy due to basal metabolism can be presented as:

W_{BM} = 4.2 kJ*24 h*60 kg = 6048 kJ

Alongside the basal metabolism energetic expenditure, there are significant costs associated with heat exchange of the body with the exterior environment. In the complex process of maintenance of a heat balance, a major importance is the intricate regulation of heat loss (Berkovich, 1964). In physiology, bodily heat transfer can be viewed as the loss of heat, freed through activities associated with living, into a cooler environment (Ivanov, 1990). There are four key modes of heat transfer between an animal and its environment: radiation, convection, conduction and evaporation; the latter being dominant in case of overheating. However, when existing under conditions of a comfort temperature zone, the greatest exchange is provided by radiation and convection (Fanger, 1970).

The total energy radiated from a unit of bodily surface area is directly proportional to the fourth power of the thermodynamic absolute temperature, as detailed by the Stefan-Boltzmann law. When there is but a small difference between the animal's epidermal temperature and the ambient temperature (as is generally the case in the Southern African part of a leopard's distribution), the equation for radiative heat loss can be presented in the following format:

$W_R = h_{rad}*S*(\delta_1 - \delta_2)*t$,

where h_{rad} is the radiative heat transfer coefficient of W_R (in m^2/ °C), S is the leopard's body surface area (in m^2), δ_1 is the leopard's epidermal temperature, δ_2 is the ambient temperature, and lastly, t is length of time over which radiation is being measured (in seconds).

By the Stefan-Boltzmann law, the radiative heat transfer coefficient h_{rad} between two gray surfaces can be determined with the equation:

$h_{rad} = \varepsilon\sigma(T_1^2+T_2^2)(T_1+T_2)$,

where ε is the emissivity of the leopard's epidermis, σ is the Stefan-Boltzmann constant ($\sigma = 5.67*10^{-8}$ W/m^2.K^4), T_1 is the epidermal temperature of the leopard and T_2 is the ambient temperature (both temperatures being absolute).

Emissivity varies with the radiation wavelength, but is close to unity at wavelengths greater than 5 μm (Ingram and Mount, 1975), therefore a value of 0.9 is here assumed for ε. T_1 is 30°C and T_2 is 26.5°C for daytime, with T_2 becoming 15.5°C average at night (as explained previously). From the abovementioned, the calculation for h_{rad} becomes:

$(0.9)(5.67*10^{-8})(303^2+299.5^2)(303+299.5) = 5.58$ during the day, and $(0.9)(5.67*10^{-8})(303^2+288.5^2)(303+288.5) = 5.28$ at night.

Therefore for W_R, we now have:

W_R = 5.58*1.53*(30-26.5)*3600 ss*12 h = 29.88 J/s *3600 seconds*12 h = 1290.85 kJ for 12 h of daytime; and W_R = 5.28*1.53*(30-15.5)*3600 s*12 h = 117.14 J/s*3600 s*12 h = 5060.31 kJ for 12 h of nighttime. This assumes the yearly average of equal day and night length, and costs 1290.85+5060.31 = 6351.16 kJ for a statistically-average 24 h period.

Transfer of convection heat occurs between body surface and air temperature and its motion (Ingram and Mount, 1975). In calculation, the biggest difficulty takes place with determination of the size of h_C (convective heat transfer coefficient), due to this value fluctuating greatly as a result of its dependency on factors such as air temperature, the shape of body form, its size, etc. The most profound influence on h_C is had by wind speed, which sets the strength of the forced convective heat transfer. In the northern Kwa-Zulu Natal, wind speed averages at about 5 ms^{-1} (Weather, 2017). At this wind speed, the value of h_C is about 690% greater than at the common indoor wind speed of 0.2 $m.s^{-1}$ (Mitchell, 1974). In an animal, convection occurs within the layer of exposed fur, which provides some insulation against the wind. However, at wind speed of 5$m.s^{-1}$, about half of this insulation will be lost (McArthur, 1981).

Since no forced convective heat transfer coefficient has ever been determined for a wild felid species, the following is an approximation (determined for a sheep by Joyce et al. (1966)):

$h_C = 7.1v^{0.5}$,

where v is the wind speed (in $m.s^{-1}$).

Substituting the wind speed of 0.2 $m.s^{-1}$, we obtain a value of 3.18 for h_C. In northern Kwa-Zulu Natal, considering the average wind speed frequent in the region, the value of h_C will be 690% greater: 3.18*6.9 = 21.91. The precise quantity of convectional heat transfer can then be determined by the equation of Newton-Richman:

$W_C = h_C*S*(\delta_1 - \delta_2)*t$ = 21.91*1.53*(30 - 26.5)*(3600 seconds*6 hours) = 2534.29 kJ for 6 h of daytime activity.

For nighttime, W_C becomes:

21.91*1.53*(30-15.5)*(3600 s*6 h) = 10499.18 kJ.

If we assume that the African leopard is a predominantly nighttime hunter, performing most stalking and chasing activities in the cooler temperatures, the animal will expend (2534.29*0.2)+(10499.18*0.8) = 8906.20 kJ. From existing literature, heat loss due to radiation and convection forms 73 to 88% of overall energetic heat losses (Ivanov, 1990); therefore it is best to assess the remaining heat-related energetic costs through relational means:

$$W_E = [(W_R + W_C)/75]*25 = [(6351.16+8906.20)/75]*25 = 5085.79 \text{ kJ}$$

From the aforementioned, the summative energetic costs attributed to heat transfer in general become:

$$W_{heat} = W_R + W_C + W_E = 6351.16 + 8906.20 + 5085.79 = 20343.15 \text{ kJ.}$$

Having accounted for both basal metabolism and heat transfer, it is important to consider the energy expenditure an African leopard is likely to incur while obtaining food. A leopard's hunt consists of a number of stages (Stander et al., 1997): regular average-speed runs (10 km/h) to detect the presence of potential prey, a period of stalking and crouching, followed by a brief sprinting phase, during which speeds of up to 60km/h (Nowak, 1999) are reached.

In case of the attempt being unsuccessful, the hunting process repeats itself all over. On average, every 1 in 4/5 hunts are successful (Bailey, 1993; Stander et al., 1997). When a prey item is killed, the leopard is likely to attempt relocating it to a competitor-free zone, dragging it at speeds of about 6 km/h (equating to about 1.7 m/s). Although there are known cases of *p. pardus* feeding on the same carcass for a few days, they often lose their kill after the initial feeding, frequently to hyenas (Creel et al., 2001).

Utilizing the aforementioned information, we can formulate a model of a standard African leopard hunt. The summative 10 km/h runs constitute a distance of about 8 km of daily movement. During this time, it initiates a maximum of 5 sprints as part of its hunting attempts, which together cover a distance of 200 m at 60 km/h speeds, an average of 40 m covered per sprint (Bothma, 1998).

In this model, energy losses associated with conversion from average to maximum speeds and back are not considered. The leopard's ideal prey of 23 kg weight is dragged at speeds of 6 km/h for an average of 320 m (Smith, 1978). Therefore, average daily runs:

$$W_1 = mv_1^2/2*t_1 = 60\text{kg}*(2.8^2\text{m/s})/2*2880 \text{ seconds} = 677.38 \text{ kJ}$$

The maximum 5 hunting sprints per day (final one being successful):

$$W_2 = mv_2^2/2*t_2 = 60 \text{ kg}*(16.6^2\text{m/s})/2*12.05 \text{ s} = 99.61 \text{ kJ}$$

Relocation of the prey carcass to a safe feeding location:

$$W_3 = (m_1+m_2)*v_3^2/2*t_3 = (60+23)*(1.7^2/2)*188 \text{ s} = 225.48 \text{ kJ}$$

Summative daily expenditure of kinetic energy on movement activities:

$$W_{kinetic} = W_1 + W_2 + W_3 = 677.38 + 99.61 + 225.48 = 1002.47 \text{ kJ}$$

Summing the leopard's overall daily energetic costs, we obtain:

$$W = W_{heat} + W_{kinetic} + W_{BM} = 20343.15 + 1002.47 + 6048 = 27393.62 \text{ kJ}$$

From the aforementioned, there is very little difference between the daily energy obtained (27625 kJ) and that used up on essential survival activities (27393.62 kJ). The small surplus of energy can either be used on particular activities which do not form part of daily routine (such as mating, territory defense, or unusually lengthy movement due associated with relocation), or can be retained for use the following day. Therefore for a statistically average African leopard, a sustained energetic balance is possible if, and only if, the biomass of prey is maintained at a level high enough to allow for successful food acquisition after at most the 5th hunting attempt. Let us consider the probability of such a situation. Marking every successful hunting sprint of a leopard with the variable p, the probability of a successful hunt after n attempts can be presented as:

$$R_{1,n} = 1 - q^n,$$

where $q = 1 - p$, and is the chance of failure.

Using this equation, the values of p can be tested from 0.5 to 0.05, alongside varying n values, the results of which are presented in Table 1. As can be deduced from Table 1, under a success rate probability of $p = 0.5$, practically four or five hunting attempts are required before a kill is almost guaranteed to be made (chances of a kill being above 0.9). Under conditions of $p = 0.3$, the number of attempts required for the same effect almost doubles; while at $p = 0.1$ there need to be at least 20 hunts to allow for at least one success, a hunting requirement that cannot be adequately met on average, if using the energetic balance determined earlier.

DISCUSSION

The results indicate that under statistically average

Table 1. Probabilities of successful hunt by a leopard under several scenarios of varying success rates (*p*) and number of hunting attempts (*n*).

n	p									
	0.5	**0.45**	**0.35**	**0.35**	**0.3**	**0.25**	**0.2**	**0.15**	**0.1**	**0.05**
2	0.75	0.698	0.64	0.578	0.51	0.438	0.36	0.278	0.19	0.098
4	0.938	0.908	0.87	0.821	0.76	0.684	0.59	0.478	0.344	0.185
6	0.984	0.972	0.953	0.925	0.882	0.822	0.738	0.623	0.469	0.265
8	0.996	0.992	0.983	0.968	0.942	0.9	0.832	0.728	0.57	0.337
10	0.999	0.997	0.994	0.987	0.972	0.944	0.893	0.803	0.651	0.401
15	-	-	-	0.998	0.995	0.987	0.965	0.913	0.794	0.537
20	-	-	-	-	0.999	0.997	0.988	0.961	0.878	0.642

leopard requirements in the African savanna, the probability of a successful kill needs to be at least $p = 0.5$ to ensure the persistence of the animal in the region (Table 1). This is due to the probability reflecting the necessary number of hunting attempts before a kill is guaranteed, which approximate four or five under $p = 0.5$ (a maximum of five hunting sprints being the basis on which the energetic calculations were made, which themselves presented a near-equilibrium between the energetic gains and losses). At lower probabilities, such as $p = 0.3$, the hunting effort required may lead to some levels of African leopard depopulation in the affected region, due to it being energetically unsustainable for the entire population to undertake almost eight hunts on average. However, it is the $p = 0.1$ scenario that is of most concern ecologically: a leopard's energy reserves are insufficient to allow at least 20 hunts on average for one to be successful, therefore predicting an absolute removal of the leopard population from the region.

From such findings, it is now possible to determine the actual stocking rates needed to sustain a leopard population of a chosen size, by using the derived probabilities of hunting success and working with the specific energy content of meat from a prey species of interest. This may be highly beneficial to game reserve managers, and important in leopard conservation overall as it allows for the reduction in the number of farmer-leopard conflicts, by meeting the leopards' energetic needs and in-turn reducing the need for leopards to leave the reserve in search of supplementary prey.

However, it is important to note that following this stocking strategy would be unlikely to eliminate all potential issues that leopards can face in a closed reserve space, with problems such as inbreeding depression and the spread of disease being common in confined felid populations (Kettles and Slotow, 2009), and not exclusively influenced by the prey number.

This paper reflects on the need to consider animal energetics when determining conservation action, showing that even a minor change in prey abundance can have potentially disastrous outcomes for predators relying on it. While there are other solutions to maintaining an adequate energy intake which predators often adopt in challenging circumstances – such as increasing the amount of food consumed per catch if prey is encountered less frequently; using the proportion of successful hunts is a convenient way to measure African leopard prey stocking rates. With habitat for leopards and their natural prey progressively declining solely to areas designated specifically for biodiversity preservation, determining successful hunts and adjusting reserve prey stocking rates in accordance will aid in maintaining stable leopard populations, and do much to alleviate farmer hostility where this is a problem, as mentioned above.

Combined with measures such as implementing alternative husbandry techniques for livestock keep and strengthening of policies guiding predator control on agricultural lands (Balme et al., 2009), leopard population reduction due to lack of prey can be effectively brought under control. With *P. pardus* research not consistently aligning with conservation priorities (Balme et al., 2013), there is a need for more applied studies addressing the factors controlling (and limiting) leopard occurrence, to effectively manage the distribution of *P. pardus* at large.

CONFLICT OF INTERESTS

The author has not declared any conflict of interest.

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Distribution and habitat suitability of Nile crocodile (*Crocodilus niloticus,* L. 1768) in Tekeze River Dam, Tigray, Ethiopia

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Understanding the spatial distribution and habitat utilization by animals play a significant role in wildlife conservation and habitat management for the benefits of both animals and communities living close to protected areas. This study was conducted to identify the distribution and habitat use of *Crocodilus niloticus* in Tekeze River Dam through qualitative and quantitative surveys based on diurnal survey, semi-structured questionnaire and geographic information system (GIS) spatial analysis methods. The Tekeze River Dam representing the study area was divided into seven stratified river stratum. All spatial data were recorded and analyzed using ArcGIS 10 software. The distribution revealed that *C. niloticus* were registered along the main river stretch and its tributaries. Majority of *C. niloticus* prefer river banks, shallow water depth and rocky ground to perform their activity patterns. Along the 71.2 km² of the study area delineated for habitat preferences, 9.78 km^2 was the highly suitable habitat while 4.63 km^2 was the least suitable. The influence on communal resources, fishery activities and irrigation practice at small-scale on river banks and increment of water level due to flooding of the Tekeze River Dam were among the primary causes of disturbances induced by human to *C. niloticus* distribution and its habitats. The perception of most respondents to the conservation of this specie was not encouraging although their presence in the river was important in keeping the ecological balance of the ecosystem. It is therefore suggested that the success of conservation programs and habitats management should focus on educating the local community to raise awareness and change their attitudes towards promoting conservation development initiatives of *C. niloticus* in the area.

Key words: *Crocodilus niloticus*, distribution, habitat preferences, Tekeze River Dam, threatened specie.

INTRODUCTION

Understanding the spatial distribution and habitat utilization of animals is very important for wildlife conservation and management for both biodiversity protection and the livelihoods benefits of communities living close to protected areas. The spatial distribution of an organism is mainly influenced by the appropriateness of the environment (Aarts et al*.,* 2008). The ecological requirement, habitat use and preferences of the concerned organisms tend therefore to play key roles in wildlife conservation and management (Aramde et al*.,* 2011; Ekwal et al*.,* 2012). Ethiopia is a large country with diverse agro-ecological zones and rich in biodiversity. However, some Ethiopian wildlife populations tend to be threatened due to habitat disturbances, hunting and environmental pollution. This is also the case with crocodiles. Worldwide, crocodiles are known as threatened species due to overexploitation, hunting or killing of animals, habitat loss, pollution and human disturbances (Ross, 1998; Fergusson, 2010; Ijeomah and Efenakpo, 2011). Among the other factors driving crocodilian population's decline includes also, invasive plant species such as alien plant (*Chromolaena odorata*) that affect breeding of *Crocodilus niloticus* in case of the Lake St and Lucia as an alien plant in South Africa (Leslie and Spotila, 2001). The loss of any species of crocodiles would therefore lead to threat on biodiversity and a decline of a key species that depend on crocodiles for survival (Fergusson, 2010). Among the well-known crocodile species along the Nile River valley includes the *C. niloticus.* It is an apex semi-aquatic predator, known as symbolic specie of a great importance to civilization of the area and serves as a model organism for international wildlife conservation. In recent times, a number of surveys on *C. niloticus* have been conducted throughout Africa and its range as well as in some areas of Ethiopia like Lake Chamo, southern part of Ethiopia on its distribution (Ross, 1998; Whitaker and Whitaker, 2007; Hekkala et al*.,* 2011).

Although there are very little studies about crocodiles in Ethiopia, however crocodiles often play a key role in maintaining and safeguarding biodiversity of wetlands. They are also considered as environmental indicator species, especially for the build-up of contaminants and as apex predators. They contribute also by playing an essential role in the nutrients recycling (Botha, 2011; Ijeomah and Efenakpo, 2011). Meanwhile, crocodiles also represent a good source of income generation through the sale of skin and its meats to tourists as well as through crocodile ranching/farming for enterprises development. The status of these species represents therefore an indicator of the overall health of wetland ecosystems. In the past, Ethiopia was known as the habitat of the largest Nile crocodile populations that occurred in the Rift-Valley Lakes and rivers. Today, the populations of Nile crocodile have declined to near extinct in the region but there is still lack of information on Ethiopian crocodiles' population, distribution and habitat preferences. This has led to the limited understanding on the human-wildlife interactions, the implementation of effective conservation strategies, habitat management and sustainable management of crocodiles' population as valuable source of income generation for local communities in the country. In addition, there is also a lack of research study assessing the population status of crocodiles such as *C. niloticus* so as to conserve, manage and sustainably utilize that specie in the northern parts of Ethiopia in general, and in Tekeze River Dam, in particular. Therefore, the purpose of this study was to determine the distribution, habitat use and to establish a baseline data of the current status of *C. niloticus* in Tekeze River Dam, Tigray, Ethiopia.

METHODOLOGY

Study area

The Tekeze River Dam (hereafter TRD) representing the study area is located in Tigray Regional National State of Ethiopia and at 142 km faraway from Mekelle (capital city of Tigray) in the west side of the study site. It is located at 13° 16' 0" N - 13° 21' 0" N latitude and 38° 42' 0" E 38° 47' 0'' E longitude with an altitudinal range of 727 to 4517 m a.s.l (Figure 1). The catchment area of Tekeze River Dam was 30,390 km^2 while the topography accounts for high peaks and plateaus as well as deep canyon gorges. Tekeze River Basin experiences a climate with a maximum temperature ranging between 21 to 43°C and a minimum falling between 3 to 19°C. In the lowlands, mean annual rainfall is 600 mm and 1,300 mm in the Simians Mountains and in the highlands of river basin. This river initially originated from North Wollo Highland covering an area of 82,350 km^2 and flowing to the West Nile directions which has annual runoff of approximately 7.6 BM^3.

Methods of data collection and surveyed

To collect all relevant data necessary for determining the spatial distribution and habitat preferences of *C. niloticus* in TRD, qualitative and quantitative surveys were carried out from November 2012 to May 2013. Diurnal shoreline survey and the geo referenced data generated from GIS and remote sensing using Google earth were used. The presence of crocodile was ascertained through visual sightings and interviews with experienced fishermen and local residents. During the study, Yemaha 40 hp boat, Binocular Celestron 10 x 50 image-stabilizing binocular and Garmin, Etrex Vista GPS were also used. All crocodile sightings positions were recorded and logged into a Gramin Geographic Positioning System (GPS). Locations were only recorded if there was at least less than 10 m accuracy on the GPS receiver. At the time of survey, basic observations were carried out like the physical and vegetative character of the shoreline, crocodile numbers, age-size classification, basking sites, swimming and prey availability by adopting methods used (Whitaker, 2007; Leslie et al., 2011). The size classifications of crocodile are determined based on modifications of methods adopted from Botha et al*.* (2011) and Combrin et al*.* (2011). Accordingly, juveniles are assigned to age-

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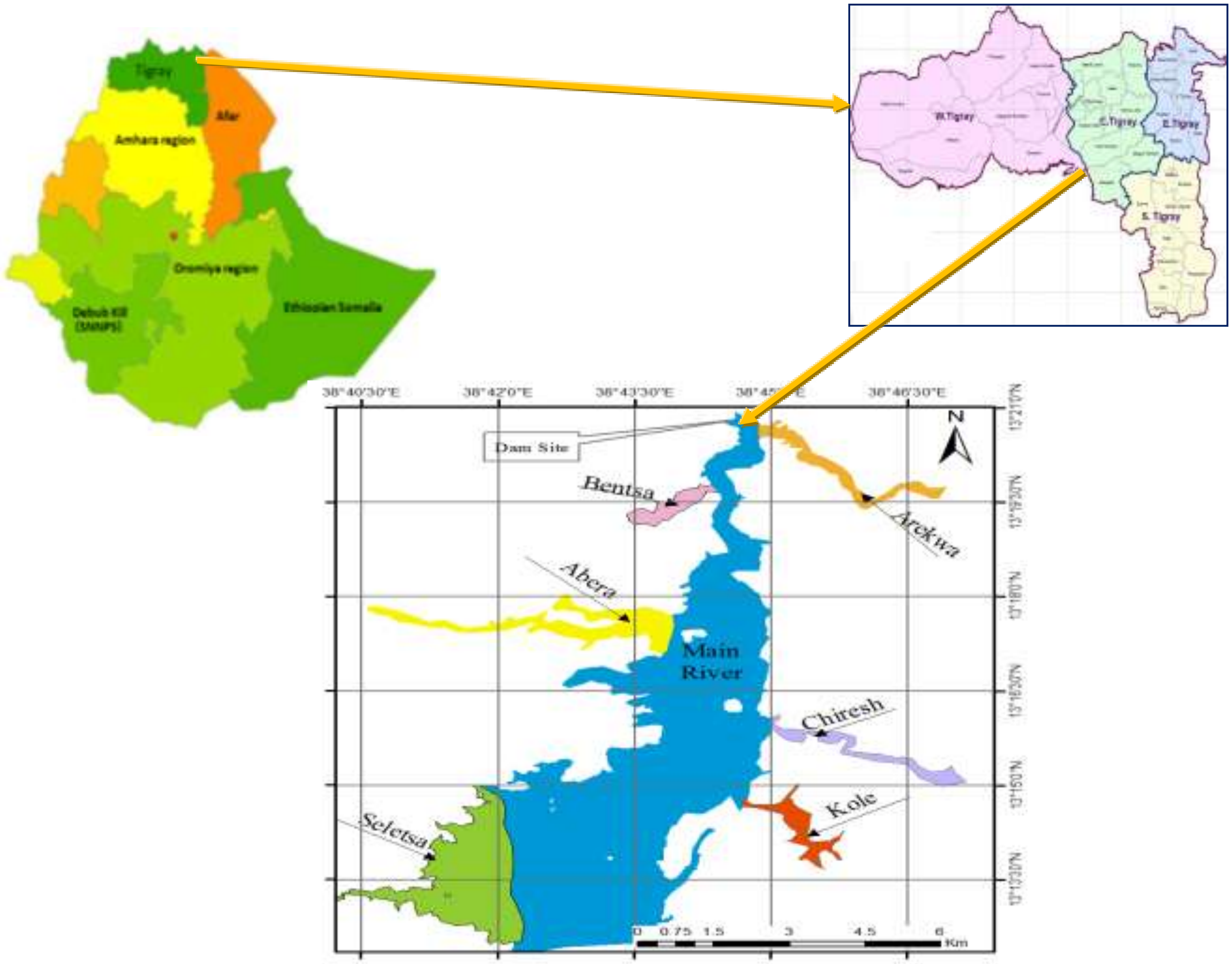

Figure 1. Map of the study area (Tekeze River, Tigray, Ethiopia). Source: ArcMap version 10.0, GIS by ESRI (2010).

size class which is less than 1.2 m; sub-adult assigned for those size classes ranges from 1.2 up to 2.5 m and adult for crocodile size greater than or equal to 2.5 m band. The study area was divided into seven zones namely: Arekwa (Zone I), Main River (Zone II), Bentsa (Zone III), Abera (Zone IV), Chiresh (Zone V), Seletsa (Zone VI) and Kole (Zone VII) based on the main river stretches and its tributaries (Figure 1). In the meantime, data were collected on each river zone to record the presences, habitat conditions and characteristics of *C. niloticus* in the study area.

Use of geo referenced data sources and analysis of area determination for mapping spatial distribution and habitats type of crocodile

To model the habitat suitability of the study area for *C. niloticus* habitation, GIS and remote sensing data were used as the main data source (Table 1). The analysis used to delineate potentially suitable habitat of *C. niloticus* were outlined. Before proceeding to the actual spatial analysis task, the area coverage has been determined using data collected from GPS shoreline survey during crocodile observational survey and Google Earth satellite imagery. By combining the two data types, the boundary of the study area has been determined. Ecological studies indicated that nesting and basking were rarely found more than 100 to 200 m distance from permanent water (Harvey and Hill, 2003). To incorporate this and identify the human interventions along the shoreline of Tekeze River, a 300 m buffer layer within the surroundings of the River had been produced using proximity analysis in Arc GIS 10 software. Hence, the areas found within 300 m of its shoreline were set to be the study area of interest (AOI). The resulting layer defines all areas within 300 m from water and was considered a potentially suitable habitat for the activity patterns of crocodiles.

Data processing and preparation

Land cover classification

A Landsat TM5 satellite image, acquired on 10 November, 2011 was used to produce a map of all cover types in the study area. The classification of cover types adhered to a subset of the scheme used by Harvey and Hill (2003) with some modifications. These cover types considered were those specific enough to reflect the

Table 1. List of input database layers created for *C. niloticus* habitat suitability modeling.

Data	Source	Function of the data
Landsat TM 5	USGS	To derive Land Cover Data
DEM	USGS	To derive Slope Layer
GPS data	Field survey using GPS	To record presences of crocodile, To identify human intervention areas
Google Earth Satellite Image	Google Earth Software	To support image classification and identification of river shore lines and centers

crocodile presences and sufficiently to include the habitat encountered in Tekeze River. Before the image classification, 4, 3, 2 and 1 band combinations was done to identify the vegetation from the other land cover types. This is because, once the vegetation were differentiated, it would be easy to identify the remaining land cover class. The resulting classification scheme having relevance with crocodile habitat suitability consisted of the following five land cover class:

1) Open water
2) Shoreline vegetation
3) Rocky ground
4) River banks with muddy ground
5) Shoreline sand beach.

Following this, a supervised image classification was done using ERDAS IMAGINE image–processing system for classification of satellites image into spectrally similar class. The accuracy level of image classification was done using 78 Ground control points sampled from the land cover classes. It has been able to maintain 87% of overall image classification accuracy results. The land cover map was then reclassified into five main classes, by giving a higher cell value for land cover classes which were assumed to be suitable for crocodile habitat. In the reclassification process, river banks were identified as the 1st suitable areas, sandy areas the 2nd, open water the 3rd, rocky ground the 4th and vegetations near shore line the 5th.

Deriving and reclassifying slope layer

Slope layer was identified as one of the influential factor affecting habitat suitability and was incorporated in the model. The slope map of the areas was derived from 30 m resolutions of Digital Elevation Model (DEM) of the study area using the Spatial Analysis Tools (SAT) of Arc GIS 10 software. This was obtained from the United States Geological Survey. Assuming that flat areas were considered more suitable for crocodile habitat selection for the purpose of basking and nesting as well as searching prey while steep areas were considered as less suitable habitat for crocodiles. Accordingly, the slope layer was reclassified into five main classes by giving higher cell values to flat areas (having a steepness of less than 5%) and assigning lower cell values to less suitable slopes (Figure 2).

Developing and reclassifying distance to human interventions areas layers

It was stated that human interventions would create disturbances on habitats suitability. *C. niloticus* habitat areas should ideally be far from areas where there were intense human activities. To take into account this factor in the model in terms of human interventions in the surrounding areas, the Tekeze River was delineated using GPS. Such areas include parts of the River where there were fishery activities, seasonal irrigated areas in the river banks, availability of grazing lands in the surrounds of the River while the River was used as source of livestock water point. Grazing is viewed as a disturbance for basking and nesting of crocodiles when performed at vicinity of crocodile habitats. Nesting sites were often trampled upon by cattle, either causing complete destruction of eggs or cattle run the risks of being attacked by crocodiles. The GPS data were imported into ArcGIS 10 software and a human intervention's area as polygon layer was delineated using the GPS data. Based on this layer, distance to grazing areas was derived using the spatial analysis extension of ArcGIS 10 software (Figure 3). The layer was reclassified into five main classes, by giving higher cell values to those areas located farthest away from human intervention's sites and areas closest to human intervention's areas were given lower cell values.

Deriving and reclassifying distance to center of River layer

It is assumed that *C. niloticus* prefers to habitate in the shallow shorelines of the lake than the center of the lake where the depth of the lake was very high. Taking this into account, the main center of the lake was determined through field survey in combination with high resolution Google Earth Satellite Images. Thereafter, distance to the main center of the lake was derived based on this data using the spatial analysis extension of Arc GIS 10 software. This distance to main center of the river layer was reclassified into five main classes by giving 5 to the cells having the farthest away distance to the center of the lake whereas 1 was given to the cells having a closest distance to the shorelines of the lake (Figure 4).

Deriving and reclassifying distance to River shore line layer

Since the shorelines of the river other than the main center of the river or hinter lands were preferred by crocodiles for habitation, therefore, the shorelines of the lake were delineated from high resolution satellite images. Distance to shoreline's layer has been estimated and reclassified into five main classes (Figure 5). In doing so, areas found close to shorelines were assigned the highest cellvalues while areas found faraway to shorelines were assigned the lowest cell values.

Combining and weighting the layers

Using the weighted overlay tool element of the Arc GIS 10 spatial analysis extension, the above data sets were combined and

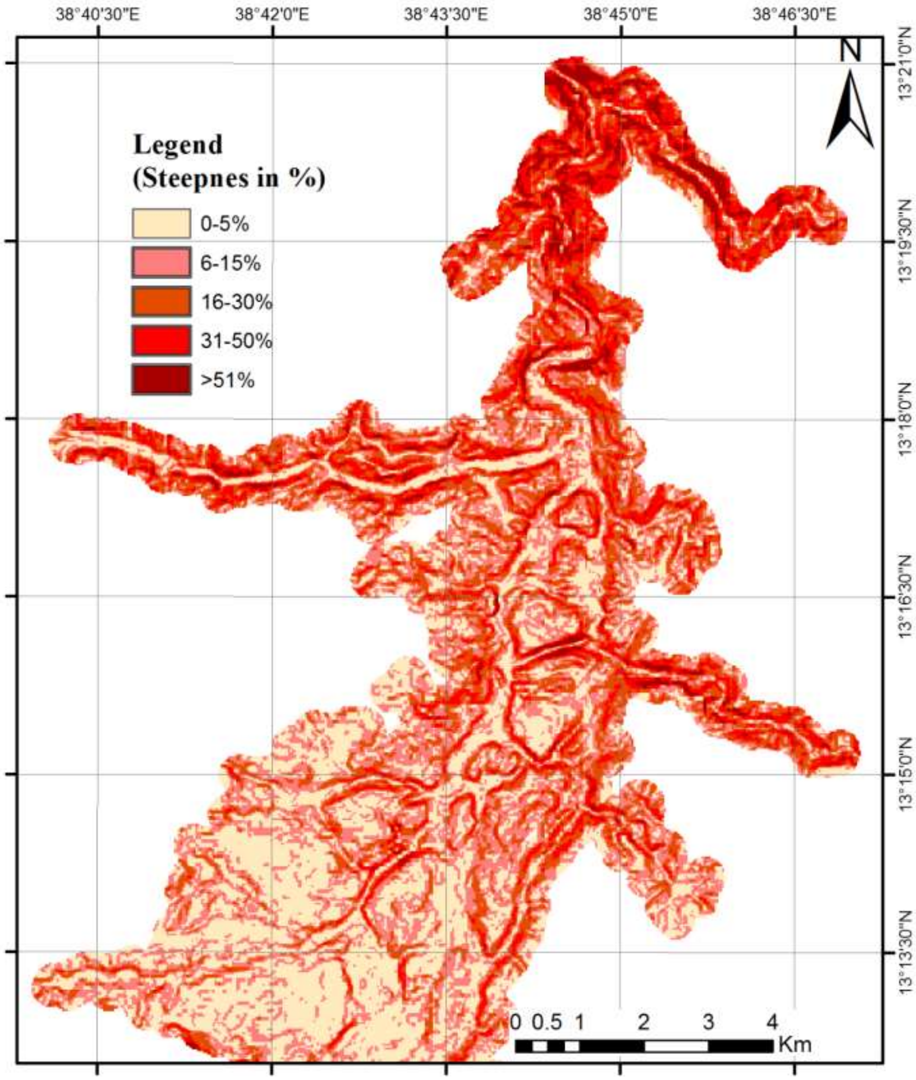

Figure 2. Slope layers of study area; Tekeze River.
Source: ArcMap version 10.0, GIS by ESRI (2010).

weighed. In the weighting process, the following percentage of influence was maintained (Table 2). This has enabled production of the habitat suitability map of the area.

Data analysis

Data were recorded and entered to excel-spread sheet 2010 prior to applying data analysis. For each of the sites section surveyed, the total numbers of crocodiles, and their distribution with respect to habitat selection and relative density (individual number/km of surveyed area) were calculated. Crocodile sighting data were analyzed to show the distribution and habitat suitability of crocodiles over the study area using Arc GIS 10 software for windows. Total mean and standard deviations of crocodile presences were calculated for all age size-classes due to the small number of crocodiles encountered in each size class by surveyed zone. All statistical analysis was conducted using SPSS (SPSS 20.0 for windows). The attributes from georeferenced data were also presented and finally the spatial distribution and habitat suitability of *C. niloticus* in TRD were given.

RESULTS

Spatial distribution of Nile crocodile along Tekeze River Dam (TRD)

A total of seven stratified zones were surveyed to determine the abundances, distribution and habitat preferences of *C. niloticus* in the study area. In total, 67 individuals of *C. niloticus* were recorded in TRD and the distribution of crocodile along the major river and its branches were presented in Table 3. The distribution of crocodiles following age class was different along the entire survey of river stratum. The total mean and standard deviation of *C. niloticus* age-class distribution was 25.33±1.5 (Table 3). The relative density of *C. niloticus* in Arekwa sites was highest (3.01/km) and least in Seletsa River stratum (0.2/km).

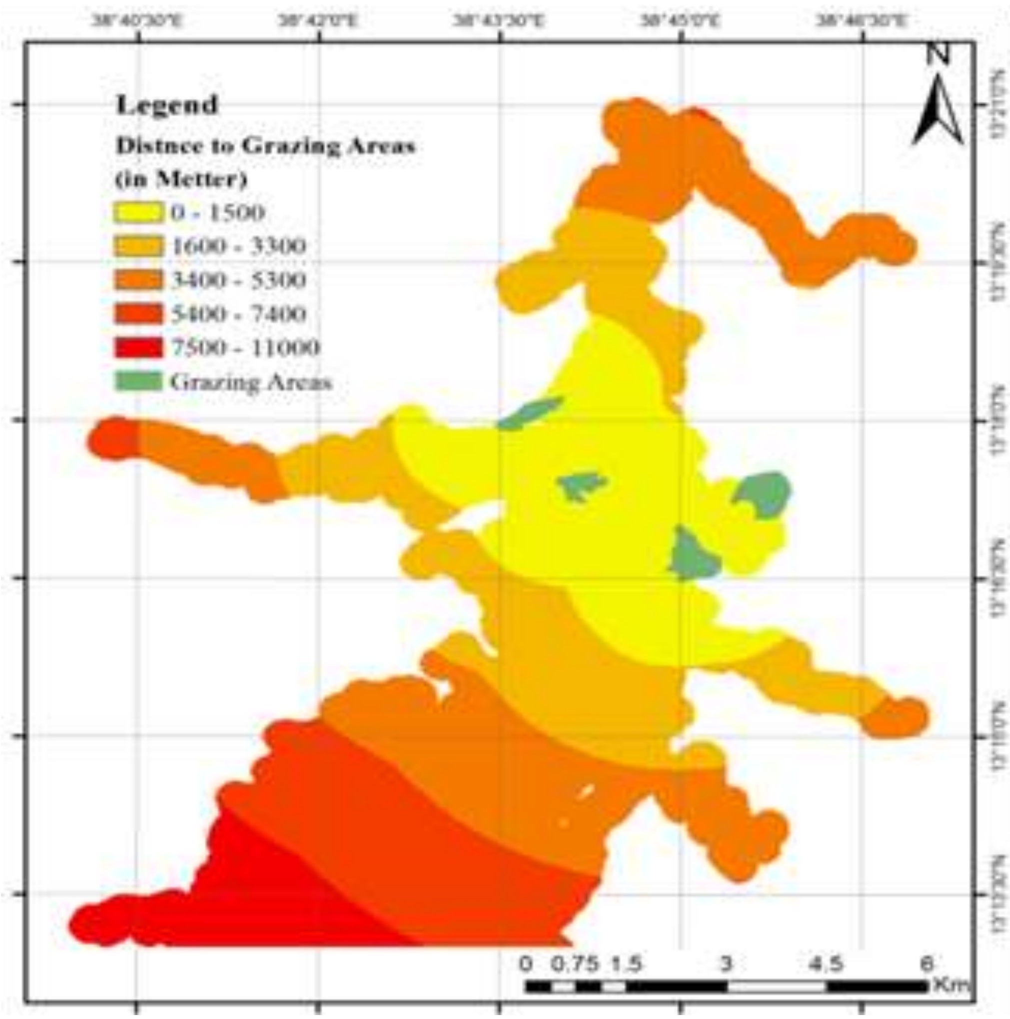

Figure 3. Distance to human intervention areas layers.
Source: ArcMap version 10.0, GIS by ESRI (2010).

Table 2. Contribution (%) of each predictor variables for habitat suitability analysis of *C. niloticus* in TRD.

S/N	Layers	% of influence
1	Land Cover Classes	35
2	Slope	20
2	Distances from the water	15
3	Distance to shore lines	15
4	Human interventions or disturbances	15

Spatial distributions of land use and land cover in Tekeze River Dam

The results of land use and land cover classifications are presented in Figure 6. The latter was generated by Landsat TM5 satellite image. This map of land use and land cover of an area presents patterns of land utilizations and also to evaluate the coverage of micro-habitat types of crocodiles in study area. Accordingly, rocky grounds were found in Arekwa, Bentsa and on the edge of main River zones of the study area. Muddy and sandy river banks were most frequently found in inlet-river channels such as Abera, Arekwa, Seletsa, Bentsa and Chiresh zones of the study area. High vegetations

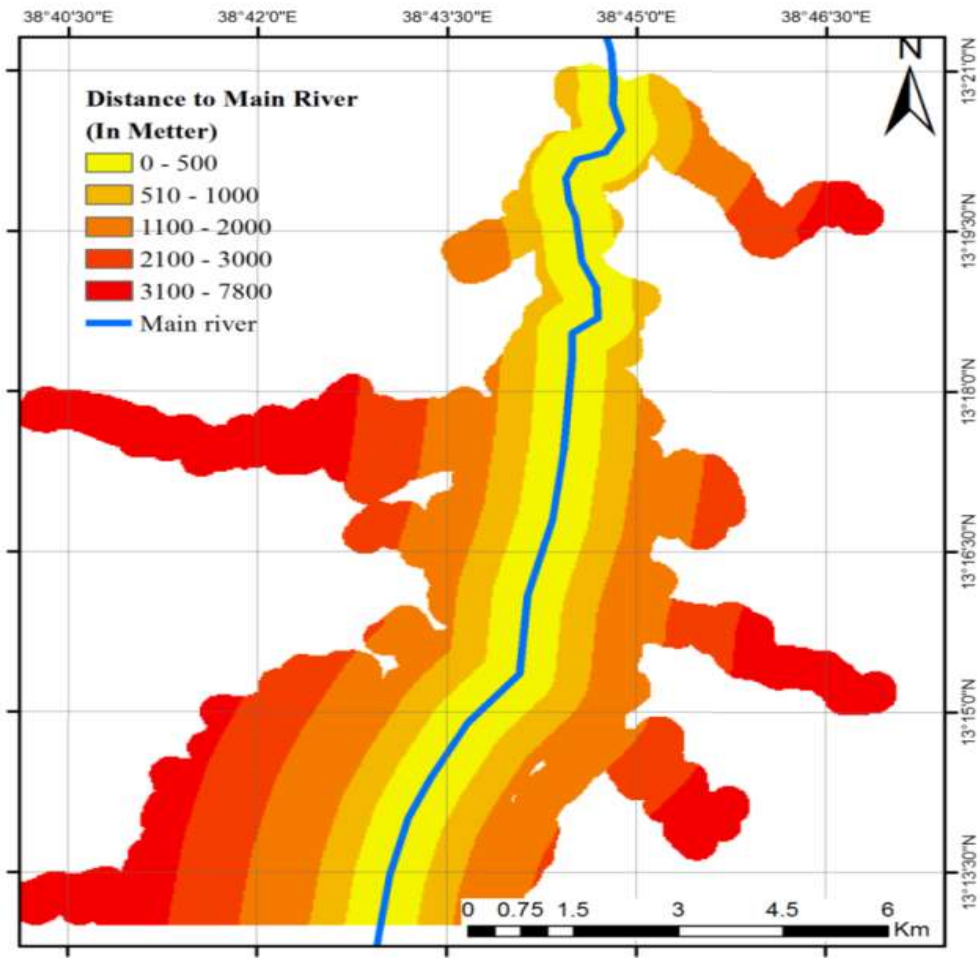

Figure 4. Distance to center of river layer.
Source: ArcMap version 10.0, GIS by ESRI (2010).

coverage was mostly common in Kole and Seletsa River stratum. The accuracy level of overall image classifications result was 87%.

Habitat preferences and frequency of observation of *C. niloticus*

The average frequency of observations of *C. niloticus* in seven river zones was different by zone. The crocodiles encountered in the surveys were either from basking sites or in shallow water. Basking sites of *C. niloticus* includes the shallow water, rocky ground with gravel soil and muddy river banks as well as on the walls of Tekeze Dam crest. With respect to habitat selection, high frequency percentage (35.8%) was observed on river banks whereas lower frequency percentage was observed on shoreline with vegetations (13.4%) (Table 4). For the present surveyed sites, the open surfaces of the stratum represented the second most common micro-habitats where 31.3% of individuals were encountered. Furthermore, all crocodiles observed during the survey were found at the upper stream inlet site of the river basin between the gorges. Crocodiles were most frequently recorded in river banks which were found in inlet-like tributaries of Arekwa as well as Chiresh zones of the current study area. *C. niloticus* was also distributed in shallow water depth at shoreline of each river stratums.

Habitat suitability analysis of *C. niloticus* in Tekeze River Dam

Along with the frequncy percentage of crocodile occurence and the suitablity of the habitat for *C. niloticus,* the spatial distribution of that specie was also analyzed in the study area (Table 5). The results show that among 71.2 km^2 of the study area delinated, 9.8 km^2 (13.75%) of the habitat data fell within areas classified as highly suitable while 4.6 km^2 (6.5%) of habitat were under the least suitable habitat.

Figure 7 represents the predicted habitat's suitablity

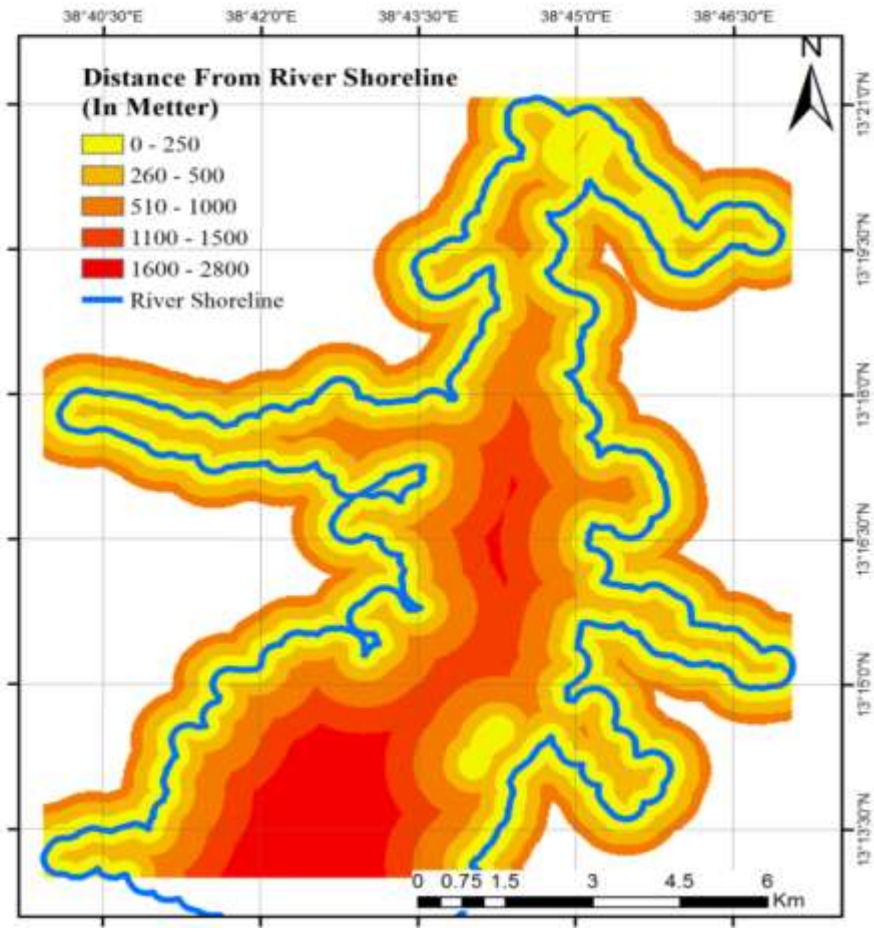

Figure 5. Distance to river shoreline layer.
Source: ArcMap version 10.0, GIS by ESRI (2010).

Table 3. *C. niloticus* recorded during Engine Boat based surveys of the TRD and its tributaries from November 2012 to April 2013.

Survey zone	Survey site	Distance covered (km)	Age-class*					Relative density (total number of *C. niloticus*/km)
			Juvenile	Sub-adult	Adult	Total	Mean±Std	
I	Arekwa	5.3	2.0	6.0	8.0	16.0	5.33±3.05	3.01
II	Main River**	25	2.0	6.0	10.0	18.0	6.0±4.0	0.72
III	Bentsa	2.1	1.0	3.0	2.0	6.0	2.0±1.0	2.86
IV	Abera	6.4	-	3.0	4.0	7.0	3.5±0.70	1.09
V	Chiresh	4.4	2.0	4.0	3.0	9.0	3.0±1.0	2.04
VI	Seletsa**	30.1	-	3.0	3.0	6.0	3.0±0.0	0.2
VII	Kole**	21.4	-	1.0	4.0	5.0	2.5±2.12	0.23
Total		95.0	7.0	26.0	34.0	67.0	25.33±1.5	1.45± 1.19

* The age class distribution of crocodile classification was based on the method adapted by Botha et al. (2011) and Combrink et al. (2011). Accordingly, juveniles listed as <1.2 m, sub-adult as > 1.2 < 2.5 m and adult were also as ≥ 2.5 m. ** The area were surveyed as shoreline since the sites have wide width length and the two sites Kole and Seletsa are the potential sites for breeding and basking area.

map of *C. niloticus* using the four layers covariates: landcover class, slope, distances from water, distances to shorelines and distances from human intervetions or disturbances. Areas of prediction of high occupancy or high suitability were found in central west, southwest and southeastern parts of the TRD and along its banks. However, the area along edges of other zones systems were considered as the least suitable habitat.

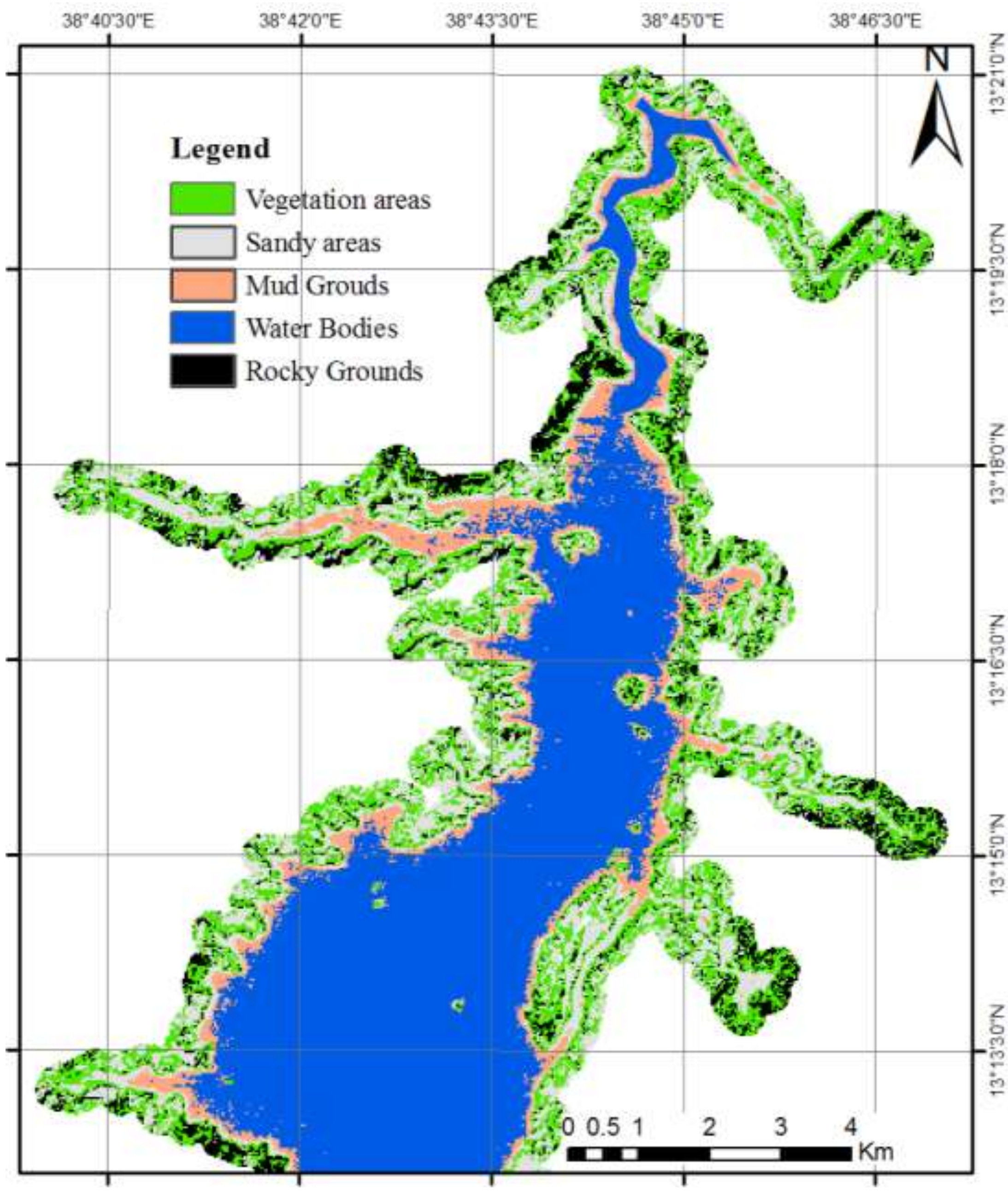

Figure 6. Land use and land cover (LULC) map of study area (The background is a Landsat TM false-color composite of the TRD).
Source: ArcMap version 10.0, GIS by ESRI (2010).

Table 4. Contribution (%) *C. niloticus* recorded in average by micro-habitat type in TRD (n=67).

Micro-habitat	% records (n=individual observation)
River Bank with muddy ground	35.8(n=24)
Rocky ground	19.4 (n=13)
Shoreline vegetation	13.4 (n=9)
Open water	31.3 (n=21)
Shoreline sand beach	0.00
Total	100 (67)

Table 5. Area under different categories of habitat suitability for *C. niloticus* in Tekeze River Dam.

Habitat type	Area (km^2)
Highly suitable habitat	9.8
Suitable habitat	28.2
Moderately suitable habitat	28.6
Least suitable habitat	4.6
Total	71.2

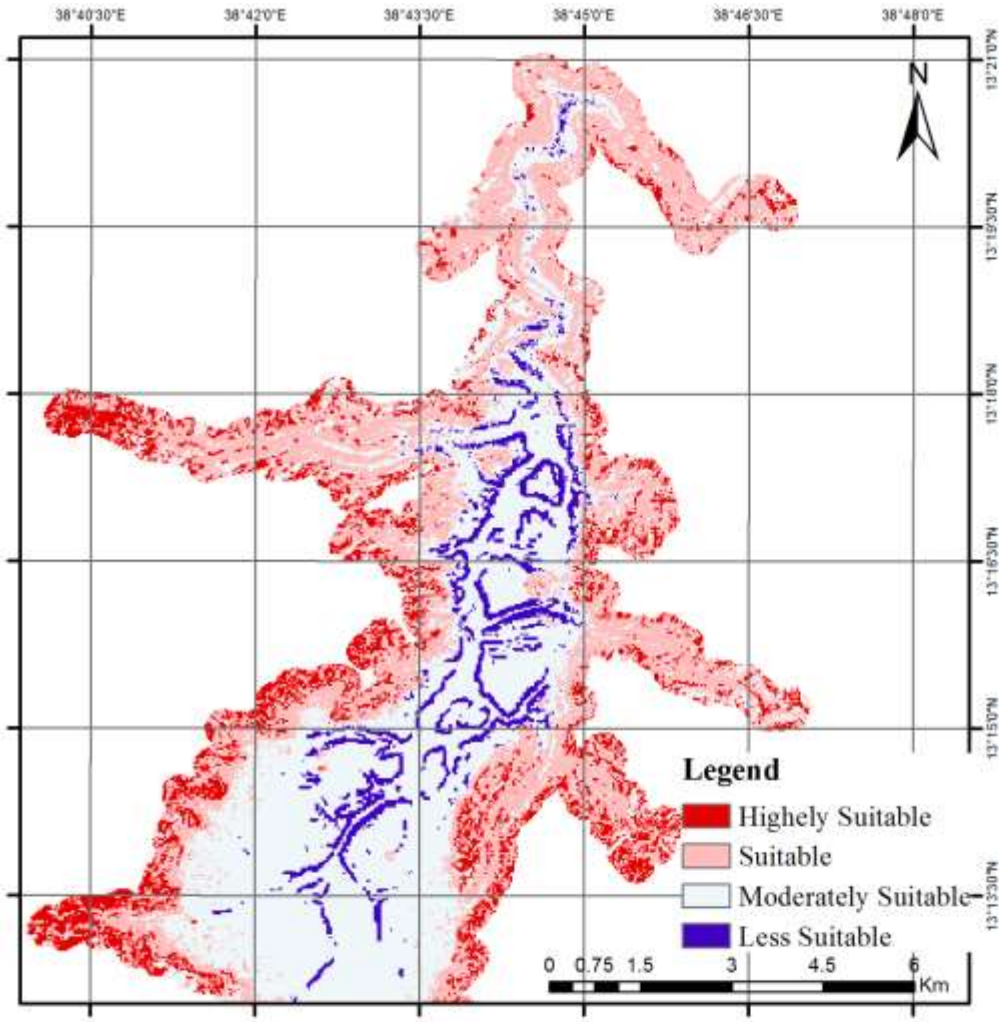

Figure 7. Representation of the predicted habitat suitability map of *C. niloticus* based on the six layers of co-variates listed in Table 3 in TRD.
Source: ArcMap version 10.0, GIS by ESRI (2010).

DISCUSSION

The priority steps towards proper conservation and management of *C. niloticus* in Tekeze River Dam (TRD) starts by evaluating the potential areas of distribution of the crocodile species and their habitat use. In the present study, a spatial distribution and habitat preference of *C. niloticus* were investigated through diurnal shoreline surveys and GIS mapping and remote sensing. The reason for surveying the land-water interface (shoreline and water's edge) is based on the assumption that the crocodile population is easily counted when out of the water (Combrink, 2004) than in the water. In addition, crocodile populations are predators of the water's edge, inhabiting shorelines rather than open water, so that crocodilian habitat could be characterized as linear as opposed to occupying a surface area. This result is in agreement with the present findings. In the present study, 67 *C. niloticus* were recorded and found to be distributed randomly in the TRD throughout the surveyed area, especially in the main river channel and its six tributaries. Compared to other studies, the number of crocodiles' occurrence were relatively small due to the remote character of the Tekeze River systems associated to constraints of logistical fieldwork.

The latter prevented the researcher to carry out the data collection during night time and in the whole Tekeze River Basin. The capacity to submerge in the water bodies and the nocturnal behavior of crocodiles has further contributed to hampering their detection. Thus, it is likely that increased sampling will detect more crocodile's population (Brito et al*.,* 2011) which in turn is important to identify their distributions and habitat preferences easily than in the present study area.

Despite their irregular distribution, the study has shown that *C. niloticus* were mainly and frequently observed in the inlet river-like areas of Arekwa, Bentsa and Chiresh as compared to other sites. The current distribution locations of *C. niloticus* are similar to the distributions of micro habitat types that existed in TRD. This result is in agreement with the finding of Gandiwa et al*.* (2013) who found that the distribution of crocodiles were not uniform in Gonarezhou National Park of Zimbabwe and its river systems. This was likely due to habitat loss, siltation of inlet-river channel, frequent boat traffic and interaction with human for the communal resources such as fish, water sources for livestock and irrigation for crop growth. *C. niloticus* were mostly found in Arekwa River-channel which was probably related to high availability of prey resources such as fish, birds, and livestock as well as due to suitability of predation in the river strata.

Additionally, the irregular but common distribution patterns of the crocodiles in TRD such as the inlet of the tributaries river is probably due to the higher water levels caused by the raising of the dam wall. The latter covers the vast majority of the other shoreline areas in the dam which represented unsuitable habitats for crocodiles. Consequently, the crocodile population in the TRD was now concentrated in those found in-let tributary river areas wherein anthropogenic activities occurs frequently. In line with the present report, Botha et al*.* (2011) have shown that uneven distribution of crocodiles was observed in Olifants River of Loskop Dam due to increased water volumes. Bourquin (2007) has also reported similar argument in the Panhandle Region of the Okavango Delta, Botswana. He pointed out that when water levels rises and concentrates in main channels in dry season, crocodilians move out of main water into the surrounding floodplains or wetlands. Moreover, Ron et al*.* (1998) have also found that water level was the most important factor affecting the spatial distribution of crocodilians in the Amazon Basin. This implies that most crocodiles remain in flooded forests during the rainy season and tend to retreat to the deepest areas of lakes when forced to do so by reducing water levels during the dry season. This indicated that there were spatial changes in distribution of crocodiles in TRD due mainly to the loss of suitable habitat driven by the increase of water levels along the dam wall. As a result, crocodiles are forced into areas where they would likely experience human-crocodile interactions than elsewhere in the river systems. Such loss of suitable habitat often leads to modification of spatial distributions of crocodiles and expose them to threats related to local people's interactions and disturbances. Therefore, focusing on the study of habitat suitability represents an important factor to monitor and understand the rate of disturbances driven by crocodiles-human interactions so that methods to minimize the effects of disturbances can be developed at critical sites and habitats.

In general, the present result on habitat suitablity of *C. niloticus* in TRD showed that out of 71.2 km^2 delineated area, 9.78 km^2 was highly suitable habitat whereas 4.63 km^2 was the least suitable one for *C. niloticus* activity's pattern while the rest were considered as unsuitable area. Overall, this means the Tekeze River is a suitable habitat for the species activity patterns due to feed availability and proper environmental conditions. This means that in TRD, the *C. niloticus* are distributed and selected in habitats wherein anthropogenic activities are high such as in Arekwa River-channel. This indicated that even though animals use habitats in a specific manner, however, the costs and benefits of using specific habitat types remain unknown for many types of organisms. The reasons driving animals' site selection are related to species-specific proximate responses to a wide range of biotic and abiotic factors that predict habitat suitability (Peterson, 2003). Other researchers have reported that *C. niloticus* use a wide variety of habitat types as an indication of an ontogenetic shift in diet including large lakes, rivers, and freshwater swamps and from insects and small aquatic invertebrates when young to vertebrate prey among larger crocodile (Wallace and Leslie, 2008; Fergusson, 2010). In TRD, despite the disturbances, river bank habitats are highly preferred by *C. niloticus* for basking followed by open river surfaces which have shallow depths and low water current. This might be driven by the fact that the crocodiles use the river banks for dual functions such as for basking and nesting. This finding is also in agreement with the work of Graham (1968) who found that crocodile's habitats are made of shoreline and littoral zones. Somaweera et al*.* (2011) have also found that most hatchlings of freshwater crocodiles (*C. johnstoni*) were found in floating vegetation mats or grassy banks rather than in the widely available open banks. Thus, it is important to develop habitat protection measures mainly on the basking and nesting areas to reduce the species-species conflict while conserving them at the same time.

The present study showed that there were no large variations among age-size classes of *C. niloticus* in the spatial distributions within survey zones of TRD. In the present study, the unusual aspect of the TRD crocodile population was the presence of different class sizes like juvenile, sub adult and adults basking together on the shore. However, it has been difficult to find evidence of cannibalism. The results of the respondents and personal observations during the survey confirmed that more than five individual crocodiles of different size class were encountered together on river banks while basking. This may be an indication of absence of threat related to cannibalism among *C. niloticus* in TRD. On the contrary, several researchers have reported that *C. niloticus* were segregated based upon individual size-dependent differences to reduce intraspecific conflicts or cannibalism (Gary and Christopher, 1985; Hutton, 1989; Hutton and Child, 1989; Bourquin, 2007). Consequently, small-sized crocodiles were separated from large ones which appeared to be a natural ecological regulation mechanism and may also be a response to the threat of cannibalisms. Additionally, Hutton (1989) has clearly explained that adults become increasingly intolerant of intermediate-sized animals and suggested that size-class separation is part of a general density-dependent regulating mechanism in crocodilian populations but not in case of Tekeze. The availability of rich food and prey resources driven by low fishing activities might explain the previous trends. The absence of cannibalism in TRD may also be another reason in determining the population ecology of crocodile in the Tekeze River population. Hence, it is necessary to verify the behavior, molecular genetics and speciation of *C. niloticus* encountered in TRD.

The visual sightings of crocodile were observed mainly at basking, swimming, and submerged positions on different micro-habitat types. River banks with exposed sun-banks were the potential area for basking like in the Arekwa sites of river stratum. This might be due to the presence of potential prey resources as well as habitats with suitable environmental conditions for crocodile activity patterns. However, with the increase in cattle grazing, the presence of drinking water areas, river side agriculture, fishing practices, noise and waves created by the boat traffic for recreational and fishing purposes in Arekwa and other sites, it has been shown that the areas previously used by crocodiles for basking and nesting have been disturbed. Such activities might have affected the distribution and population size of the crocodiles. The latter obviously need to be contained in habitats such as basking and nesting areas. Similar to the present finding, Zisadza-Gandiwa et al. (2013) have showed that human-wildlife conflicts on communal areas, pollution from agricultural activities upstream, and poor land use in the catchment leading to siltation and limited availability of prey resources have all contributed to affect crocodile population size and structures. Therefore, forcing crocodiles to sub- and/or non-optimal habitats can have catastrophic effects on the crocodile populations, alimentary behaviour, population recruitment, survival and rise up human-crocodile conflicts. For example, during the study, respondents have described the negative impacts of crocodile on local communities' livelihoods due to attack and killing of the livestock and removal of fish from nets. As result, local communities hunt them as sign of retaliation. Similar trends were also reported from (Thomas, 2006; cited in Bourquin, 2007) in Botswana. He found that the habitats selected by the *C. niloticus* were also the exact locations preferred by the local communities for meeting their livelihoods needs. Overcoming such threats on local communities' livelihoods calls for monitoring, interpreting and mapping the critical crocodile nesting areas, basking, feeding and juvenile habitats on a regular and systematic basis to develop innovative and balancing conservation and development initiatives in TDR area.

Conclusion

This study explored the distribution of *C. niloticus* and mapped out its potential habitat in Tekeze River. The *C. niloticus* registered in the main river and its tributary branches were not uniformly distributed. The visual sightings of crocodile were observed mainly at basking, swimming, seeking and submerged positions on different micro-habitat types. River banks with exposed sun-banks are the potential area for basking. Overall, main river stretches of Tekeze River were known by its large distribution of small and medium-sized classes of crocodile. There is no record of small-sized crocodile observed in Kole sites of study area. Along the 71.2 km^2 of the study area delineated for habitat preferences, 9.78 km^2 was the highly suitable habitat while 4.63 km^2 was the least suitable. The influence on communal resources, fishery activities and irrigation practice at small-scale on river banks and increment of water level due to flooding of the Tekeze River Dam were among the primary causes of disturbances induced by human to *C. niloticus* distribution and its habitats. Local communities along riverine systems of Tekeze Dam perceive *C. niloticus* as a sole enemy of their livelihoods and their property.

Recommendations

Further research needs to be conducted with regards to mapping of spatial and temporal analysis of *C. niloticus* distribution along the river systems with shoreline riparian vegetation classification of Tekeze River. Also, a combination of daytime and spotlight surveys will need to be conducted to know their status since the species is cryptic, secretive and nocturnal in its behavior. To overcome human-crocodile conflicts, it is necessary to monitor, understand and plan the critical crocodile nesting areas; also, basking, feeding and juvenile habitats on a regular and systematic basis are needed to develop the TRD area. It is therefore suggested that the success of conservation programs and habitats management should focus on educating the local community to raise awareness and change their attitudes towards promoting conservation development initiatives of *C. niloticus* in the area.

CONFLICTS OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Land use/cover change analysis and local community perception towards land cover change in the lowland of Bale rangelands, Southeast Ethiopia

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Changes in ecosystem functions can be analyzed through changes in land use land cover (LULC) systems. This study was carried out to analyze the LULC changes and perception of local community towards land cover change in the lowlands of Bale, Southeast Ethiopia using remote sensing data, field observations and perception of local people. The results showed that cultivated land, settlement, bush land and bare land expanded by 13.81, 14.30, 12.62 and 22.3% respectively, between 1986 and 2016, whereas wood land, grassland and shrubby grassland declined by 33.82, 24.4 and 3.36% respectively. Local communities' perceptions indicate that climatic, demographic and anthropogenic factors as well as implementation of inappropriate government policy and development interventions were major driving forces of LULC dynamics. Environmental and local livelihoods implications such as rangeland degradation, bush encroachment, soil degradation, livestock loss, biodiversity loss and poverty increase resulted from these changes. Cumulative effects contribute to rangeland degradation and poverty. Therefore, to halt the impact of LULC disturbance and its implication on the likelihood of the pastoralist, appropriate management measures and government policies have to be implemented.

Key words: Bale rangelands, remote sensing, land use/cover change, socio-economic factor.

INTRODUCTION

According to Dong et al. (2011), range land ecosystem supports over one billion herds of camel, cattle, sheep and goats and over 200 million pastoral households. Rangelands biomes encompassing much of the area where pastoral livestock production is a major land use, cover 51% of the earth's land area (Mussa et al., 2016).

Extensive livestock production is the main land use activity in rangeland areas, and due to this it's been referred to as pastoral land. Curtin and Western (2008) and Mussa et al. (2016) describes rangeland to the specific values such as providing daily and seasonal forage, carbon sequestration, water resources, breeding grounds to wild animals and livestock which are some of the services from rangelands; while Little and McPeak (2014) describes rangeland ecosystem as an entail of various resources with many ecological, social and economic values.

Globally, rangelands are under intense pressure from

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natural and human induced factor. Climate changes, demographic factors, crop focused policy, and investment policy are some of the factors attributed to land use land cover (LULC) changes in rangelands (Tsegaye et al., 2010; Abate and Angassa, 2016). Since 1950, about 10.7 million km^2 of the world lands occupied by grassland and woodland have been changed to farmlands (Tsegaye et al., 2010; Kimiti et al., 2016).

The rapidly increasing of LULC changes in the rangelands of Ethiopia and the increased complexity of their drivers are presenting substantial problems for rangeland management. The magnitude of the changes can be quite different depending on the anthropogenic influences in specific areas (Roques et al., 2001; Mwavu and Witkowski, 2008).

As such, the integrity of rangelands is subsequently declining with reduction in the quality and quantity of services they provide to dependent communities (Mussa et al., 2016). Monitoring LULC changes is essential for understanding vegetation dynamics and utilizations of natural resources in a sustainable manner (Gibbens et al., 2005). Such information is also very crucial to enhance the formulation of informed policies to support sustainable rangeland management and rehabilitation practices for increased natural resource protection, resilience of rangelands to changing climates and pastoral livelihoods (Zziwa et al., 2012).

Bale rangelands comprise of important cultural landscapes, and livestock has been an integral part of Bale landscape for many centuries. Decades ago, the Bale rangelands were considered as one of the most productive ecosystems. However in the 1970s, the largest loss of pastoral resources occurred with the establishment of the Bale Mountains National Park (Fiona et al., 2008).

Anthropogenic and naturally induced factors are the prime causes for rangelands degradation (Abate et al., 2010), consequential it is disturbing the delivery of ecosystem services and goods (Caldas et al., 2015). These changes also affects livestock mobility, grazing areas and the conflicts over natural resources (Egeru et al., 2014). Restricted mobility is known to lead to increased grazing pressure that predisposes soil to erosion, and lowers rangeland productivity and livestock production (Msoffe et al., 2011).

Studies conducted on LULC changes gave more emphasis on analyzing LULC or on socio-economic surveys (Abate, 2011; Eyob et al., 2011; Amanuel and Mulugeta, 2014) rather than linking LULC changes with socio-economic surveys. For instance, according to Tsegaye et al. (2010) mapping spatial changes using remote sensing can only give quantitative descriptions than explaining the relationship of patterns of change and the driving forces.

Meanwhile, understanding local community perception on LULC changes is crucial for designing effective land use plan (Wubie et al., 2016). Though studying spatial change of LULC using remote sensing tools and local community perceptions are vital for ensuring sustainable rangeland ecosystem management; thereby improving the livelihood of pastoralists in the region.

However, studies on LULC changes through integrating remote sensing tools with the perceptions of local communities in lowlands of Bale rangelands are lacking. Therefore, this study was focused on analyzing LULC changes and perception of pastoralists on LULC changes in Raitu district of Bale rangeland of Southeast Ethiopia. And so the study was intended to examine the LULC changes between 1986 and 2016; and the perceptions of local community towards LULC changes in the lowlands of Bale rangelands, southeast Ethiopia.

MATERIALS AND METHODS

Study areas

This study was conducted in the lowlands of Bale rangeland of southeast Ethiopia, Raitu district. The district covers a total area of 5426 km^2. The district was found at 625 km from Addis Ababa and 195 km from zonal capital Robe. It is located between latitude 6° 20′ 0″ and 7° 25′ 0″ N and longitude 41°30′00″ and 42°00′00″ E (Figure 1). The altitude of the district is within the range of 500 to 1785 masl. The climate varies from hot to warm sub moist plains (Sm1–1) in the sub agro ecological zone. The area experiences bimodal rainfall pattern (1200 tp 2600 mm) with average rainfall of about 450 mm, mean annual temp with 25°C, and vegetation dominated by wood, savanna and grass lands (Abate et al., 2010).

Data collection for LULC changes

A sequence of different satellite image of Landsat images obtained from Global Land Cover Facility (GLCF) archive (https://www.landcover.org) were analyzed to study LULC change. For preparing LULC for the year 1986 and 2001, LULC Landsat Thematic Mapper 5 (TM) of 30 m resolution acquired on February 9, 1986 and January 30, 2001, and for the year 2016 Enhanced Thematic Mapper plus (ETM+) image acquired on January 12, 2016 were used. Since a single image did not cover the spatial extent of the entire study area, two scenes of images (path/raw 168/056 and 168/057) were mosaic on a band-by-band basis and masked by the study area boundary.

To avoid the adverse effect of cloud cover on LULC classification, satellite image with less than cloud cover images taken during the dry season was used, and the selection of imageries depended on their availability (Abate and Angassa, 2016). Moreover, topographic map (at a scale of 1:50000), which covers the entire study area, was obtained from the Ethiopian Mapping Agency, and Google earth map was used as supplementary ancillary data for classification and accuracy assessment (Figure 1).

Several steps were employed in processing the images. These included pre-processing, design of classification scheme, preparation of false color band composition and unsupervised classification of the images, and validation of image classification (Figure 2). The pre-processing (for example, haze reduction, linear stretching, and histogram matching) was used to enhance visualization and interpretation (Abate and Angassa, 2016).

TM and ETM+ Landsat images were orthorectified to Universal Transverse Mercator (UTM) projection WGS 84 datum, UTM zone 37. 1986 image was used as reference to the geometric correction and image-to-image registering. The 2001 image was co-registered

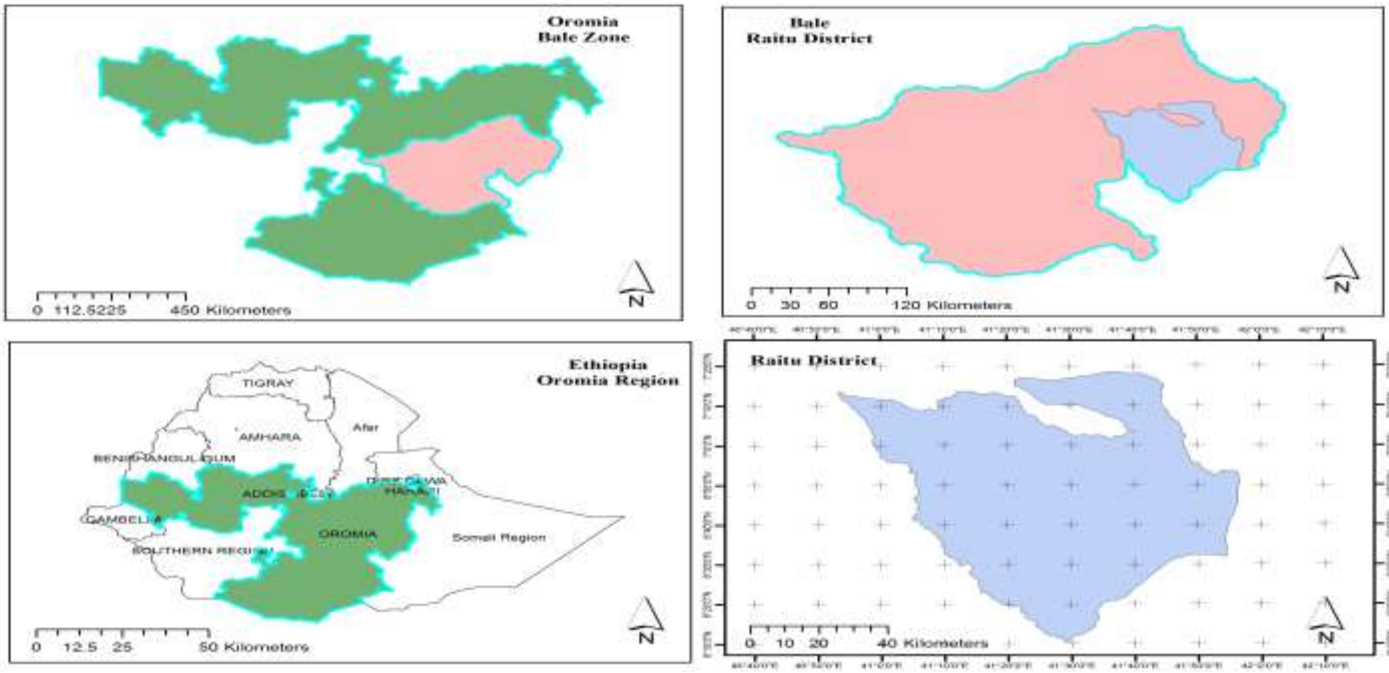

Figure 1. Map of the study area (Raitu district, lowlands of Bale rangelands, southeast Ethiopia).

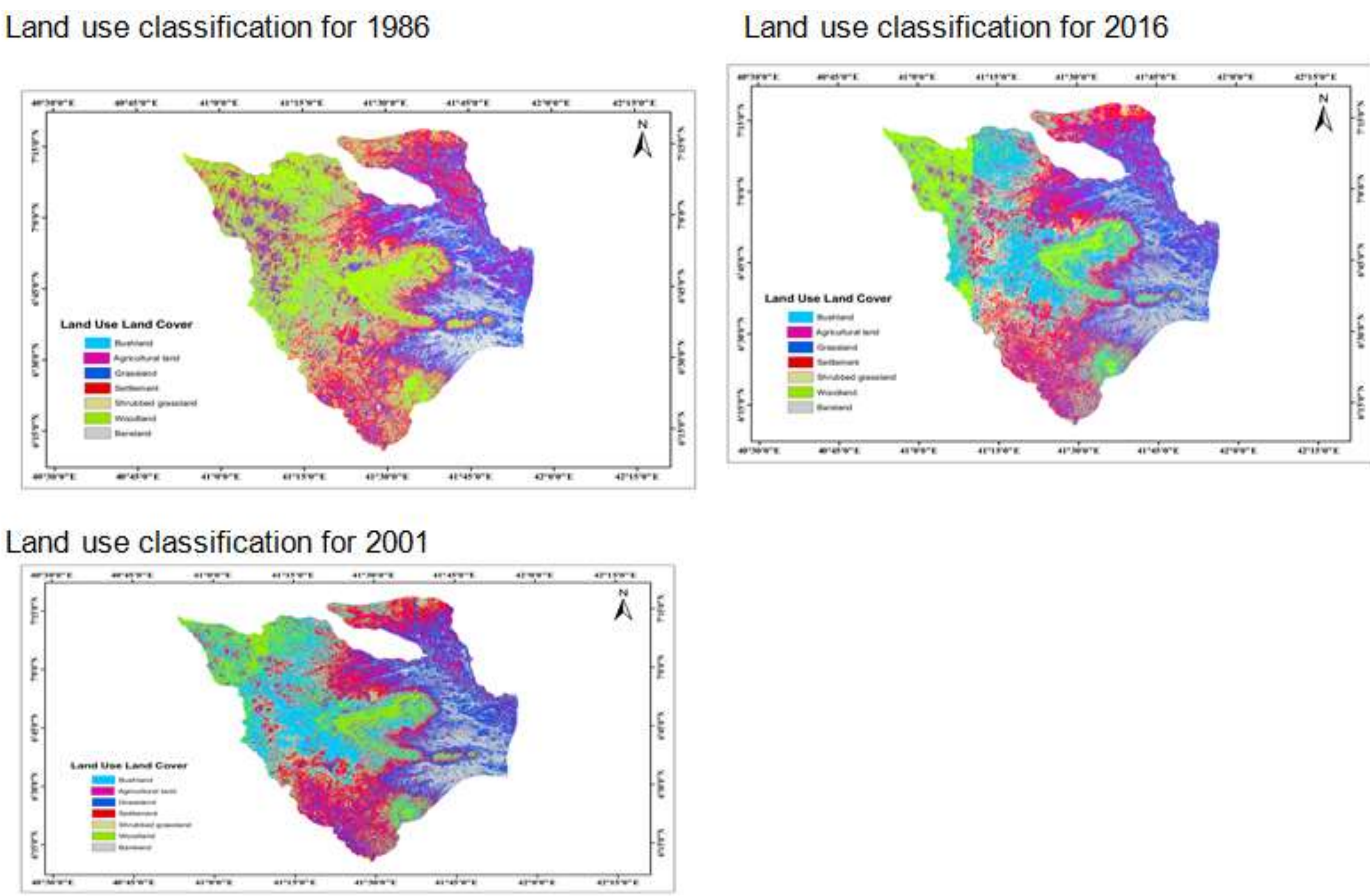

Figure 2. LULC change classification map of 1986, 2001 and 2016 in Raitu districts, southeast Ethiopia.

Table 1. Land use and land cover class nomenclature used in the study area.

Land use/cover class	Description
Woodland	Land with woody species cover >20% (height ranges 5 to 20 m), areas with trees mixed with bushes and shrubs, with little use especially for cattle. Those sites where woody cover is fully mature and herbaceous plants have been almost eliminated
Bushland	Land with >20% bush or shrub cover (<5 m in height)
Shrubby grassland	The shrubed grasslands are former grassland sites where shrubs and bush have increased in density to be co-dominant with herbaceous plants in terms of cover
Grassland	Grassland with <20% bush or shrub cover, grass and herb cover with scattered trees and shrubs, areas with permanent grass cover used for livestock grazing including communal and protected areas.
Cultivated land	This unit includes cropping area
Bare land	Areas with no vegetation, which occur in rangelands including gullies and exposed rocks.
Settlement	Urban and rural settlements in the study area

with the 2016 image with a root mean square of less than 0.5 pixels.

To evaluate and validate LULC classification about 455 global positioning system (GPS) ground truth data that consists of 210 for 2016 map, 140 for 2001, and 105 for 1986 map were collected from field. The ground truth data for the years 1986 and 2001 were collected in consultation with the local people regarding the history of land use and driving forces of changes.

The nomenclature of LULC classes used in this study were adopted from the classification scheme used by previous studies (Getachew et al., 2010; Tsegaye et al., 2010; Abate and Angassa, 2016) in arid rangelands of north-eastern and northern Ethiopia. For the sake of simplicity, land class nomenclature was modified into seven classes as presented in Table 1.

Socio economic data collections

Based on accessibility, representativeness of grazing land and livestock potential of five peasant associations out of 19 were selected purposively in gathering of information related to pastoralist community perception towards LULC change cause and effect.

A combination of structured and semi-structured questionnaire interviews was conducted with randomly selected households (HHs) from those five kebeles. The interviews included a total of 200 HHs (5% of the total HHs in five kebeles) from the complete lists of HHs provided by the selected kebeles. Prior to the formal survey, a pilot survey was conducted to identify target communities and to pre-test the questionnaire to ensure that all questions were clear to potential respondents before the actual data collection.

Furthermore, information on responses that appeared unclear and complicated was clarified through conducting focus group discussions (FGDs) and key informant interviews (KIIs). A total of 5 FGD were held using a specific checklist. The participants were from different social groups, that is, kebele elders (men and women), youths, natural resource experts, vegetation ecologists, kebele chairpersons, pastoralist and agro-pastoralist leaders, and development agents and government officials.

Key informant selection was based on the information gathered from knowledgeable elders and local administrators; most of the participants were elderly people who have a good knowledge on the histories of LULC change in the area. A checklist of open-ended questions related with LULC changes, drivers behind LULC changes, and associated consequences were raised during the key informant interviews. A total of 30 key informants (four households per kebele and two experts) were included during the study. Furthermore, published documents and public statistics were also used to document the major causes and associated consequences.

Data analysis

Image classification and accuracy assessment

A hybrid of unsupervised and supervised classification methods were employed to classify the image and produce the LULC map. The supervised classification was done using the training site derived from unsupervised classification and ground truth data. Unsupervised classification was also used to provide preliminary information about the potential spectral clusters to be assigned to thematic classes. Accuracy assessments of maps were determined using error matrix and Kappa statistic (Congalton and Green, 2008). The validation for the classified maps of 1986, 2001 and 2016 were done using ground truth data of 70, 122, and 220, respectively which were gathered during the fieldwork. At each ground truth point, discussions were held with the local elders who were familiar with LULC classes to recall about LULC history covering the 1986, 2001, and 2016 periods.

Land cover change analysis

After Landsat images of each year were classified and labeled independently, LULC change was done using a post classification comparison method, and then a comparison was made using an overlay procedure (Lu et al., 2004; Abate and Angassa, 2016). Total area (TA), changed area (CA), change extent (CE), and annual rate of change (CR) variables were used to determine the magnitudes of change in terms of LULC. The variables were calculated as follows (Addis, 2010; Abate and Angassa 2016):

$$CA = TA_{(t_2)} - TA_{(t_1)}$$
$$CE = (CA/TA_{(t1)}) * 100$$
$$CR = CE/(t_2 - t_1)$$

where t_1 and t_2 are the beginning and ending time of the land cover studies conducted.

Remote sensing image analysis software ERDAS Imagine was used to do the image processing and classification. Change detection analysis was carried out using ArcGIS 10.5 by comparing

Table 2. Area coverage and rate of LULC changes between 1986 and 2016 in the in Raitu districts rangelands of southeast Ethiopia.

LULC	1986	2001	2016	1986-2001			2001-2016			1986-2016		
	km^2	km^2	km^2	CA km^2	CE (%)	CR (%)	CA km^2	CE (%)	CR (%)	CA km^2	CE (%)	CR (%)
WL	985.3	824	652	-161.3	-16.37	-1.09	-172	-20.87	-1.39	-333.3	-33.82	-1.12
BL	1465.9	1515	1651	49.1	3.35	0.22	136	8.98	0.59	185.1	12.62	0.42
SGR	1224.1	1260	1183	35.9	2.93	0.19	-77	-6.1	-0.407	-41.1	-3.36	-0.11
SET	1090.1	1136	1246	45.9	4.21	0.28	110	9.68	0.65	155.9	14.30	0.47
CL	1274	1368	1450	94	7.38	0.491	82	5.99	0.399	176	13.81	0.46
GL	1252.2	1044	946	-208.2	-16.62	-1.11	-98	-9.386	-0.63	-306.2	-24.4	-0.81
BAL	734.32	879	898	144.68	19.7	1.31	19	2.16	0.14	163.68	22.29	0.743
Total	8026	8026	8026	-	-	-	-	-	-	-	-	-

WL= Woodland, BL= Bushland, GL= Grassland, SGR= Shrubby grassland, BAL= Bare land, CUL =Cultivated land, SET= Settlement, CA= Changed area, CE =Changed extent, CR =Annual rate of change.

two classified land cover maps; that is, land cover for 1986, 2001 and 2016. The summaries of the areas and percentages of land cover change are presented in Table 2.

Socio economic data

Qualitative data collected from works appraisal, FGDs, and KIIs were gathered, organized and associated using summary tables into dissimilar themes addressed during this study. This information was used to interpret and clarify qualitative data collected from household interviews. The Statistical Package for the Social Sciences (SPSS v.20) was used to analyze data collected from semi-structured questionnaires (Wairore et al., 2015). Descriptive statistics such as means, standard deviation (SD) and percentages were used to present the results.

RESULTS AND DISCUSSION

Magnitude of LULC changes

The land use/cover change analysis made for the two consecutive periods 1986 to 2001 and 2001 to 2016 indicated that the rangeland was subject to considerable land use land cover changes (Table 2 and Figure 2). Seven major LULC categories: woodland, bushland, shrubby grassland, grassland, cultivated land, bare land and settlement were identified as depicted in Table 1. The results indicated that for the last thirty years studied, similar changes in LULC were seen for all land cover types except that of the shrubby grassland cover (Table 2 and Figure 2).

Woodland was significantly reduced by 16.37% during the first phase (1986 to 2001), and by the rate of 20.87% during the second phase (2001 to 2016). In general, the woodland cover was decreased at a rate of 33.82% annually during the study period (Table 2). The results of this study are in line with several studies that documented a decline in wood vegetation cover in Ethiopian rangelands (Tsegaye et al., 2010; Belay et al., 2014; Yonas et al., 2016).

The present result indicates that the decline in woody vegetation was attributed to excessive human exploitation for firewood, charcoal production, construction and land clearing for crop production. This is also evident in most East African countries where areas under forest cover were converted to grazing land, farmland or used for charcoal production (Olson et al., 2004; Yonas et al., 2016). Similar trends have been observed in rangelands of southeast Ethiopia, and we are losing the most important woody species from time to time (Abate et al., 2010).

Results also show that the bush land cover significantly increased by 3.35 and 8.98% during the first (1986 to 2001) and the second (2001 to 2016) phases of the study, respectively (Table 2) corroborating several studies conducted in arid and semi-arid rangelands (Takele, 2007; Tsegaye et al., 2010; Abate, 2011; Abate and Angassa, 2016) that showed the encroachment of bush. Bushland expanded annually at the rate of 12.63% during the study period (Table 2).

Abate and Angassa (2016) reported the expansion of bushland in Borana rangelands, where the process negatively affects the livelihood of Borana cattle herders. Increase in bushland cover in Bale rangelands is also in agreement with previous reports (Walkaro, 2007; Abate et al., 2010). The increase in cover of bushland might be due to the ban of fire and continued human disturbances linked to overgrazing practices (Abate et al., 2010; Tsegaye et al., 2010; Abate and Angassa, 2016).

The shrubby grassland cover was significantly increased, by 2.93% during the first phase of the study (1986 to 2001), but showed rapid reduction at a rate of 6.1% during the second phase (2001 to 2016). Over all, the shrubby grassland cover showed significant decrease annually at a rate of 3.36% (Table 2). The decline in bushy grassland cover which is attributed to excessive human exploitation of the important woody species for firewood and construction, and land clearing for crop production (Yonas et al., 2016).

Grassland cover was significantly decreased; by 16.6 and 9.4% during the first second phases of the study, respectively; that is, from 1044 km^2 in 2001 to 946 km^2 in 2016 (Table 2). Generally, the grassland cover showed rapid reduction at an annual rate of 24.4% during the study period (1986 to 2016) (Table 2). The rapid reduction in grassland cover was similar to previous reports from Afar and Borana rangelands (Tsegaye et al., 2010; Abate and Angassa, 2016).

The decline in grassland cover was observed due to ban of fire, bush encroachment, drought, expansion of cultivation, settlement and continued human disturbances linked to overgrazing practices (Abate et al., 2010; Abate and Angassa, 2016). On the other hand, the increase in grassland in different rangelands was reported from areas of the country, where the restoration activities by different government and non-governmental organisations (NGOs) were common (Elias et al., 2015). This suggests the importance of restoring degraded rangelands for improving grass cover (Walkaro, 2007; Abate et al., 2010) (Table 2). Results show that bare land cover was rapidly increased by 19.7 and 2.6% during the first and second phase of the study, respectively (Table 2). The bare land cover increased from 879 km^2 cover in 2001 to 898 km^2 in 2016 (Table 2).

Generally, bare land cover was increased at a rate of 22.3 % annually during the study period (Table 2). The result of this study is in agreement with the findings of previous studies from arid and semi-arid rangelands (Tegegn et al., 2011; Elias et al., 2015;Yonas et al., 2016), which reported high levels of bare soil in the rangelands.

Cultivated land was substantially increased throughout the study periods; the expansion of cultivated land was higher by 1.41% in the first phase (1986 and 2001) than the second phase (2001 to 2016), which accounted for 5.99%. Between 1986 and 2016, the extent of changes in the cultivated land was considerably increased at a rate of 13.8% annually, from 1274 km^2 cover of the landscape in 1986 to 1450 km^2 in 2016 (Table 2).

According to Fiona et al. (2008), the expansion of agricultural land is associated with increasing number of immigrants. Farmland expansion phenomenon is the characteristic of the country; during the past 30 years there were areas of high farmland expansion in Ethiopia (Tsegaye et al., 2010; Belay et al., 2014; Elias et al., 2015). Meanwhile, Ethiopian government has encouraged pastoralists to engage in agro-pastoral activities. This government policy and weakening of the local institutions are also intensifying factors for expansion of cultivation (Belay et al., 2014; Abate and Angassa, 2016).

Prior studies conducted in pastoral areas of Ethiopia, including pastorals of Bale, reported the change in pastoral way of life (Tsegaye et al., 2010; Elias et al., 2015). Thirty years back, livestock production was practiced by 94% of families and the inhabitants were totally pastoralists (Abate et al., 2010). This suggests that the Bale pastoral way of life is gradually shifting from more dependence on livestock keeping to crop cultivation in some locations.

Settlements land cover was constantly increased both in the earlier phase (1986 to 2001) and second phase (2001 to 2016) of the study. Between 1986 and 2016, the extent of changes considerably increased at a rate of 14.3 % annually, from 1090.1 km^2 cover of the landscape in 1986 to 1246 km^2 in 2016 (Table 2). Government settlement policy, state sponsored resettlement policy and conflicts are responsible factors for increasing settlements. The state-sponsored resettlement program, which was meant to ensure food security of highland food insecure households, has relocated millions of such households to rangelands. This resettlement policy has been pointed out as a major factor for increasing the land under settlement (Fiona et al., 2011; Mussa et al., 2016).

For example, following the 1984 famine, large numbers of families from Hararghe have been moved to the Bale lowlands. Due to the differences in land use practices of new comers from local conditions, integrating them to the local situations is very difficult. Many of the newcomers are agriculturists, who have sped up the cultivation of land at the expense of pasture (Worku and Fiona, 2017). This study is in line with the previous work conducted in northern Afar, which reported high influx of migrants from the Tigray highlands, particularly after the severe 1984/85 drought (Tsegaye et al., 2010).

Causes of LULC changes

Majority of the respondents (36%) ranked climate related factors as the first order of importance. All types of land use and land cover including the services are highly affected by the rapidly changing world climate (Opdam et al., 2009). The effect of droughts on rangelands was widely reported by different scholars (Abate et al., 2010; Tache and Oba, 2010).

Drought affects vegetation cover through suppressing grass and stimulating bush land cover, which in turn leads to a decline in grassland and shrubby grassland (Abate and Angassa, 2016). The alteration of original landscape highly affected habitat for grazers, and forced pastoralists to change the composition of their livestock.

Table 3. Perceptions of the local community on LULC changes in the study areas (N = 200).

Major driving forces	Frequency	Percentage (%)
Climate related factors	73	36
Demographic factors	56	28
Anthropogenic factors	29	15
Inappropriate policies	24	12
Inappropriate development interventions	18	9
Total	200	100

Table 4. Impact of LULC changes as ranked by respondents in the study area (N = 200).

Impacts	Frequency	Percentage (%)
Rangeland degradation	63	31.5
Biodiversity loss	48	24
Decline of livestock per household	33	16.5
Low performance of livestock	18	9
Livelihood income diversification	16	8
Conflict on rangeland resources	11	5.5
Change in livestock composition	7	3.5
Decline of traditional natural resource management	4	2
Total	200	100

Moreover, droughts also have negatively impacted the landscape causing further degradation, as people sought alternative means of survival such as cutting of trees to prepare charcoal.

Further, the variation in inter-annual rainfall amount causes differences in vegetation cover mainly by altering the grassland state to the woodland and bushland states (Abate and Angassa, 2016). This has been observed in Ethiopia in the last 50 years as the annual average minimum and maximum temperature were increasing by about 0.25 and 0.1°C, respectively, every decade (INCE, 2001; Mussa et al., 2016). This is mainly adverse in arid environments as plant productivity is strongly dependent on rainfall variability (Angassa and Oba, 2008). Overall, climate variability is probably a potential driver of LULC and rangeland fragmentation.

Tsegaye et al., (2010) and Abate and Angassa (2016) describe demographic factors related to population growth as among the underlying causes for LULC changes. Accordingly, 28% of the respondents classified the overall demographic factors as the second order of importance. The present results are in line with previous studies such as Abate et al. (2010) and WLRC (2016). Census data indicate that the population in Raitu district increased from 33,163 in 2011 to 40,316 in 2014 (Misganew, 2014). This implies that demographic expansion and consequent agricultural expansion are the major driving forces of land use cover changes. This study also has identified that the continuing increase of human population brought substantial changes on existing rangeland resources mainly on the use of woody plants for construction purposes, fuel wood, and charcoal. About 15% of the respondents ranked anthropogenic factors (overgrazing, sale of firewood and charcoal extraction) as the third main driving forces. Similarly, census results confirmed the increase in livestock that is, the total number of livestock heads increased from 36,160 in 2000 to 69,906 in 2007 and 123,152 heads in 2016.

The results of this study are generally in agreement with those reported by Abate and Angassa (2016) and Tsegaye et al. (2010) which indicated the importance of anthropogenic factors in the observed changes. Other sources (Elias et al., 2015; Mussa et al., 2016; Wubie et al., 2016) also reported the change in LULC due to anthropogenic factors.

Inappropriate government policies (that is, ban of fire, promotion of crop cultivation, settlement policies, and introduction of peasant association) and inappropriate development interventions (private investors and appropriation of private pasture lands) comprises of the consecutive ranks (Table 4). Angassa and Oba (2008) also reported inappropriate government policies as the main causes of LULC changes. Development interventions such as private investors and appropriation of private pasture lands were reported as the causes of the changes.

Impacts of LULC changes

The pastoralists were well aware of the impacts of LULC changes and listed rangeland degradation (31.5%), biodiversity loss (24%), decline in livestock per household (16.5%), low performance of livestock (9%), diversification of livelihood income (8%), conflicts on rangeland resources (5.5%), change of livestock composition (3.5%) and decline of natural resource management institutions (2%) as some of the associated impacts.

The results of this study are in line with a study conducted in lowland of Bale rangelands by Abate et al. (2010). According to Abate et al. (2010), the anthropogenic and increased human activities are the major factors causing degradation of rangelands in Raitu district. Shrinkage of grazing lands and the decline of grazing conditions due to the expansion of crop cultivation were also reported in the arid and semi-arid rangelands of Ethiopia (Abate and Angassa, 2016).

According to the result of the study key informant interviews, the variety of pastures, diversity of habitats and tree cover declined due to the rising grazing pressure resulted from restricted herd movements and excessive utilization of natural resources. Disappearances of the preferred forage species reported by respondents indicate that the decline in quality of pasture as grazing area has deteriorated over time. The study conducted by Abate et al. (2010) also indicated decline of important grass species due to grazing pressure in Raitu rangelands.

Through influencing the traditional mobility pattern of movement between the wet and dry season, grazing area land use/cover changes affect ecosystem functioning in the rangelands. Consequentially, this may also lead to a decrease in the size of dry season grazing areas, isolation of crucial habitats such as permanent water sources, particularly for large wild animals, indirectly resulting in changing livestock species composition and directly disturbing some plant species that may be threatened with extinction. The decline of important woody plant species was mainly a consequence of intense livestock browsing (Tsegaye et al., 2010), indicating the severity of degradation. Most pastoralists no longer keep cattle, and are forced to rear small stock and camels that can utilize bush encroached areas (Abate and Angassa 2016).

In conditions where key resource dry-season grazing areas are encroached by agriculture, grazing-induced degradation often occurs in other areas as they are heavily utilized during the dry-season (Tsegaye et al., 2010; Daniel et al., 2017). The indigenous natural resource management practices, such as conflict is restricted due to the dynamics of the rangelands. In different pastoral areas of the country, the rangeland resources are changing from time to time due to inappropriate development interventions and inappropriate government policies (Abate and Angassa, 2016; Daniel et al., 2017). These changes resulted in a decline of indigenous natural resource management (Daniel et al., 2017) (Table 3).

In addition, the shrinkage of rangelands from the aforementioned processes result in the conflicts of the pastoralists on rangeland resources (Bekele, 2010; Daniel et al., 2017). The rapid encroachment of agrarian community towards the rangeland ecosystem forced the pastoralists to lose their grazing land and livestock herds (Western and Nightingale, 2003; Okolle and Kioko, 2011). The changes forced pastoral households to switch to alternative livelihoods. Poverty, food insecurity, weak traditional institution, searches for alternative livelihood income and income diversification (that is, promotion of cultivation, petty trade, and changes in composition livestock species) were also some of the associated impacts.

CONCLUSION AND RECOMMENDATIONS

The results of this study findings showed considerable dynamics in land use land cover between1986 to 2016 (last 30 years). Cultivated land, settlement, bush land and bare land expanded by 13.81, 14.30, 12.62 and 22.3%, respectively; whereas, woodland, grassland and shrubby grassland declined by 33.82, 24.4 and 3.36%, respectively.

Climatic, demographic and anthropogenic factors as well as inappropriate government policy and inappropriate development interventions were major driving forces. The LULC dynamics has critical implications on the deterioration of rangeland, biodiversity loss, bush encroachments, decline of livestock asset at the household level, change in composition of livestock, soil erosion, and shortage of firewood and construction materials. The dynamics in LULC also negatively affect the key pastoral resources, which in turn greatly affects pastoral community livelihood, and puts the pastoral production system under increasing threat. The loss in key pastoral resources increasing from to time due to the rapid encroachment of bush, settlement and cultivation of potential grazing lands (shrinkage of key pastoral resources) will increase, unless strong measures are taken.

Addressing socio-economic and environmental challenges of the local areas as part of a solution to the surface problem of LULC changes in rangelands is very crucial. For sustainable rangeland management, incorporating indigenous and scientific information is very crucial. In the future, analysis of the changes in vegetation and soil from different land use, and analyzing vegetation changes using multi-temporal satellite data are highly recommended. Analysis of land use suitability and land potential are also very crucial to guide policy makers.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Ecological niche modeling and strategies for the conservation of *Dialium guineense* Willd. (Black velvet) in West Africa

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***Dialium guineense* is a multipurpose species useful in many respects. It is used in agroforestry and the trade of most of its organs is source of income for rural populations. Despite the high interests of this species to populations, we do not know much about how its spatial distribution could be impacted by climate change and which strategies to implement for its sustainable use and conservation. In order to overcome these challenges, MaxEnt was used to model the ecological niche of *D. guineense* and different decision thresholds were used to interpret and classify the outputs. Climate will impact the distribution of *D. guineense*. Indeed under Africlim rcp 4.5 horizon 2055, the predicted stable areas of species distribution will be about 73% of West Africa when the threshold of the minimum training presence is considered and will decrease to 12% when the threshold of the maximum training sensitivity plus specificity is considered. Under Africlim 8.5 horizon 2055, the corresponding values for the stable areas of the species are, respectively 70 and 8% of the study area. In comparison with the global results of West Africa, in Benin, *D. guineense* will be less threatened by climate change. As strategies for sustainable use and conservation of the species, growing and introducing it in its favorable areas to account for its absence or low densities, is recommended. Also, building capacities to the users of the species so that they can grow it on their farms is recommended.**

Key words: *Dialium guineense*, ecological niche modeling, biodiversity conservation.

INTRODUCTION

Despite its utmost importance to the survival of humanity, biodiversity is submitted to threat of habitat destruction, ecosystem overexploitation, invasive alien species, climate change, and pollution (Millenium Ecosystem Assessment (MA), 2005; CBD, 2011; Şevik, 2012; Şevik et al., 2012; Şevik and Topaçoğlu, 2015; Yigit et al., 2016). In certain continents, for example Africa, these threats are furthermore exacerbated by

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many developmental challenges such as endemic poverty, complex governance, limited access to capital including markets, infrastructure, and technology, ecosystems degradation, complex disasters, and conflicts (Boko et al., 2007). Warming trends in temperature and climate related extremes such as heat waves, droughts, floods, cyclones, and wildfires are being observed at global scale and across regions (Boko et al., 2007; IPCC, 2013, 2014). These effects are known to particularly affect poorest regions like several African countries, impacting agricultural production and causing risks of ill-human health and death. They will aggravate water stress and inundation and impact ecosystems' composition, structure, and functions. This will result in food insecurity, loss of biodiversity and ecosystems goods, functions, and services provided to people (Boko et al., 2007; Bentz et al., 2010; IPCC, 1997, 2014). Under climate change threat, species might respond in different ways. For example, species might survive in the margins of their actual range, track or colonize new areas where ecological conditions are more suitable or might even go extinct (IPCC, 1997, 2014; Hannah et al., 2007; Blach-Overgaard et al., 2010; Sanchez et al. 2011; Abrahms, 2017). In order to address the threat of climate change to biodiversity, it is important to advance our knowledge on species geographic distributions and the factors that govern their spatial patterns.

It is known that climatic and physical factors impact the geographic distributions of species at different spatial scales (Soberón and Peterson, 2005). At large spatial scales, climate is considered more relevant than biotic interactions in determining species' geographic distributions (Pearson and Dawson, 2003). Based on this, the approach of ecological niche and species distribution modeling (ENM and SDM, respectively) use the relationship between species occurrence points and their related environmental variables to describe the ecological niche (climatic preferences) and the potential spatial distribution of species (Peterson et al., 2011). Such ENM and SDM approaches are currently widely used in biogeography, conservation biology and ecology (Stockwell and Peterson, 2001; Segurado and Araújo, 2004; Pearson et al., 2007; Elith et al., 2011). For examples, Fandohan et al. (2015) modeled the vulnerability of protected areas of Benin to possible invasion of *Lantana camara* (invasive species native to South America) under current and future climates; Adjahossou et al. (2016) assessed the effectiveness of protected areas through the prediction of potential favorable areas for the cultivation and conservation of some tree species of socio-economic importance in Benin; Idohou et al. (2016) used niche models to identify potential spatial priorities for the conservation of wild palm species across West Africa; Gbètoho et al. (2017) applied ecological niche models to predict the suitability and ability of some pioneer forest species to restore secondary forests in Lama forest reserve in Benin. All those studies showed the usefulness of the ENM/SDM approach for providing information that can derive in adequate strategies to conserve species, communities, biomes, and biodiversity as a whole at national, regional or more global scales.

Dialium guineense commonly named black velvet or velvet tamarind belongs to the family of Fabaceae-Cesalpinioidae (Orwa et al., 2009). It is a multipurpose species useful in many respects. The species is used in agroforestry and is believed to restore soil fertility in fallows (Ewédjè and Tandjiékpon, 2011). Its fruits have high nutritional potentialities and selected micronutrients (Ayessou et al., 2014). It is recognized that the crude leaf extracts of *D. guineense* exhibit some anti-vibrio activities and significant antioxidant and antimicrobial properties (David et al., 2011; Ogu et al., 2013). The leaves of this species are also used to cure many diseases such as diarrhea, cough, stomachaches, malaria fever (Ogu and Amiebenomo, 2012). Its wood is said to make good firewood and charcoals (Orwa et al., 2009; Ewédjè and Tandjiékpon, 2011). The stems of the species are used in water ponds for fish-farming purposes and the trade of its fruits, firewood and charcoal is a substantial source of income for rural populations (Ewédjè and Tandjiékpon, 2011). Despite those high interests of *D. guineense* to populations, we do not know much about how its spatial distribution could be impacted by climate change and which strategies to implement for its sustainable use and conservation in West Africa [our landscape of interest (LOI)] and particularly in Benin. In order to achieve that purpose, this study aimed at addressing the following research questions: in the context of climate change, under different scenarios (IPCC, 2013); (i) what is the extent of stable (suitable both at present and in the future) areas for the spatial distribution of *D. guineense*? (ii) What is the extent of unsuitable (both at present and in the future) areas for the spatial distribution of the species? (iii) What is the extent of the areas of the spatial distribution of the species that are suitable at present but unsuitable in the future? (iv) What is the extent of the areas of the spatial distribution of the species that are unsuitable at present but will become suitable in the future? Answering those questions will surely help us address our main research objective that is to identify and set in place adequate strategies to contribute to the conservation and sustainable use of the multiple resources of *D. guineense*.

MATERIALS AND METHODS

Data sources

Study species and presence data

The natural distributional range of *D. guineense* encompasses many parts of Sub Saharan Africa (Orwa et al., 2009; Ayessou et al., 2014) where it is found in humid dense forests, dry dense forests, and forest galleries (Ewédjè and Tandjiékpon, 2011). In its natural range, the species is submitted to a temperature ranging from 25 to 32°C and a mean annual rainfall of 900 to 3000 mm (Ewédjè and Tandjiékpon, 2011). Its habitats distribution was studied in Benin by Assongba et al. (2013). According to their main results, the species was found in *D. guineense* and *Sida acuta*-community that grows on farms, gardens, and fallows; in *D. guineense* and *Berlinia grandiflora*- community in savannas; and in *D. guineense* and *Celtis zenkeri*-community in semi-deciduous and gallery forests. The occurrence data we used in our study were downloaded from GBIF site in October 2016 (http://doi.org/10.15468/dl.bn7vpz). A final dataset of 947 georeferenced records was retained to run models with MaxEnt (Phillips et al., 2006) after cleaning efforts that consisted in eliminating: occurrences data lacking geographic coordinates and those falling outside West Africa, our landscape of interest.

Environmental variables

Fifteen bioclimatic variables (bio1-bio7 and bio10-bio17) were downloaded from Wordclim site (Hijmans et al., 2005; http://www.worldclim.org/current) at a resolution of 2.5 arc minutes (approximately 5 Km at equator). Those data cover the time period 1950-2000 (Hijmans, 2005). Corresponding projection environmental layers were downloaded on Africlim site (Platts et al., 2014; https://webfiles.york.ac.uk/KITE/AfriClim/GeoTIFF_150s/) under rcp4.5 and rcp8.5, horizon 2055. Only 15 projection environmental layers (bio1-bio7 and bio10-bio17) are available on Africlim site, and this justifies why we relied on Worldclim to choose the corresponding environmental layers for the present. Africlim environmental layers for projections were considered advantageous over that of Wordclim because they are more adapted to the ecological realities of Africa than the pixel resolutions of general circulation models (Platts et al., 2014). Moreover, the general circulation models have less confidence simulating surface temperature at regional levels than at larger scales and the precipitations are not simulated at regional scales because of uncertainties in observations (IPCC, 2013). In Africlim ensembles derived from two Regional Circulation Models, a range of observational baselines were used to empirically downscale the models outputs to resolutions that can capture environmental local variations and are therefore useful for ecological applications at local scales (up to 1 km) (Platts et al., 2014). According to Soberón and Peterson (2005) four classes of factors affect the distribution of species: 1) abiotic factors in terms of climate, topography, soils; 2) biotic factors such as interactions between species (competition, mutualism, diseases); 3) accessibility of the species to the area studied (availability of seeds and dispersers, absence of barriers) from original distribution areas in ecological time; 4) evolutionary capacities of species to adapt to new environment. Taking into account the case of *D. guineense* with respect to those four classes of factors affecting and explaining its actual distribution, we inferred that the actual area where the occurrence points are sampled globally defined its region of accessibility and represent the region (M) on the Venn Diagram of Soberón and Peterson (2005). According to Barve et al. (2011), M has important implications in model training as it represents the area where background points are sampled. According to the same authors, M also affects the model validation because, the larger its extent, the better the model predicts suitable areas of the distribution of a species. The specification of M is also important in model comparison because it impacts the relative similarity of niches sampled from that space (Barve et al., 2011). We considered that region (M) as our Landscape of Interest (LOI) and clipped the environmental layers to that LOI (Figure 1). As we know, one fundamental limitation to presence-only data is sample bias whereby some areas in the landscape are sampled more intensively than others (Phillips et al., 2009). In order to account for that, we considered that in West Africa, where the species grows, the countries don't inventory or publish their data at the same rate / intensity; we therefore added bias grids on a scale of 1 (less effort in inventorying and publishing data) to 4 (most effort in inventorying and publishing data) to represent sampling efforts across the LOI (Elith et al., 2011) (Figure 1). This enabled us to provide a bias file to run MaxEnt.

Model fitting

We used MaxEnt to achieve our modeling purpose. In order to calculate the probability of the species' presence, MaxEnt uses background data which are randomly sampled in the LOI (Phillips et al., 2006, 2009). According to Phillips et al. (2009), the purpose of selecting background data is also to characterize the environmental factors shaping the geographic distribution of presence records. That approach is important for presence-only data since it alleviates bias in samples and improves the prediction performance of models (Phillips et al., 2009). The MaxEnt method is however somehow limiting as the reliable estimation of the probability of the presence of a species over a LOI requires true-absence data (Soberón and Peterson, 2005; Pearce et al., 2006; Soberón and Nakamura, 2009). It is however known that MaxEnt has a better predictive ability than other algorithms like the Genetic Algorithm for Rule-Set Prediction (GARP) (Pearson et al., 2007). It is indeed evident that in general, MaxEnt predicted a larger proportion of the presence of species and is therefore more helpful in exploration purposes designed to discover new distributional areas of species (Pearson et al., 2007). With respect to the types of the data, MaxEnt also performed well compared to a set of algorithms (Genetic algorithm for Rule-Set prediction, Generalized linear models, Boosted regression trees, Random forests) in predicting the relationship of species to environment, mapping predictions, and extrapolating predictions beyond the training data (Elith and Graham, 2009).

In order to run MaxEnt, we converted the environmental layers into ascii format using QGIS 2.16.2. We used the default value 1 as regularization multiplier (beta value). We then proceeded to the selection of appropriate environmental variables. For that purpose, the Receiver Operating Characteristic (ROC) curve and its related Area Under Curve (AUC) (Phillips et al., 2006), the percentage contribution table of variables, and the Jackknife charts were taken into account to judge the most important contributing variables to the models and these were bio3 (isothermality), bio4 (temperature seasonality), bio12 (annual precipitation), and bio15 (precipitation seasonality). In order to run MaxEnt, we used the following settings options: 25 as value of random test percentage; 10,000 as maximum number of background points; remove duplicate presence records. The remaining options were set to default.

The models simulating climate changes are based on scenarios of anthropogenic forcings (IPCC, 2013). In the framework of the fifth assessment report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), a new set of scenarios, the Representative Concentration Pathways (RCPs), was used for the new climate model simulations led by the Coupled Model Inter comparison Project Phase 5 (CMIP5) of the World Climate Research Program. The magnitude of projected changes in climate is substantially affected by the choice of emission scenarios (IPCC, 2013). Four RCP scenarios are used within

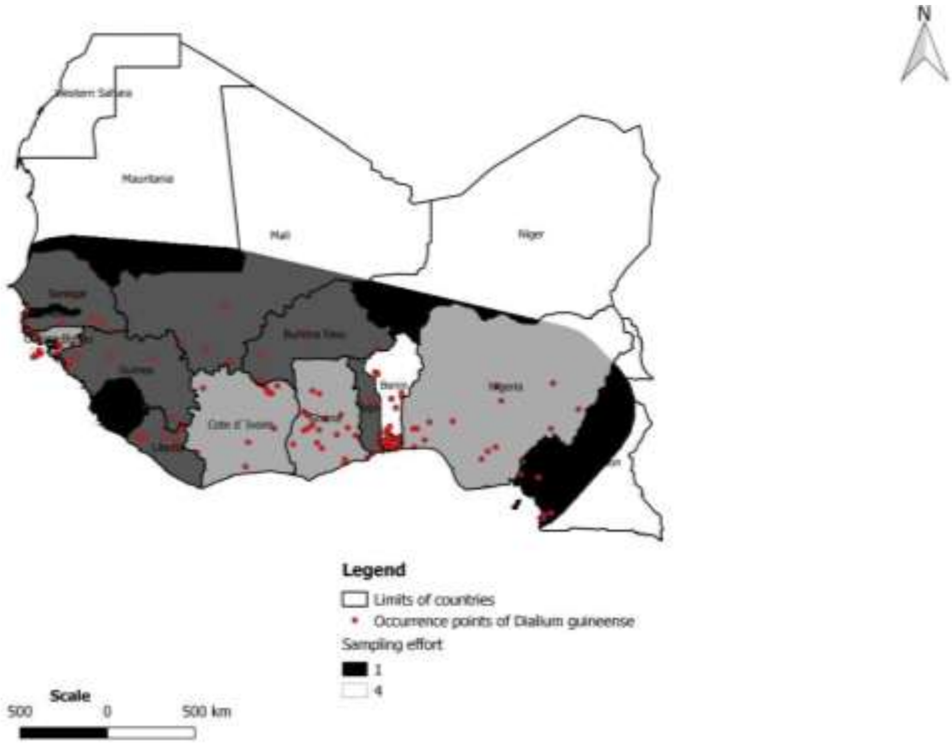

Figure 1. Occurrence points and sampling efforts of *Dialium guineense* across the Landscape of Interest (LOI). Data derived from GBIF.org (27th October 2016) GBIF Occurrence Download http://doi.org/10.15468/dl.bn7vpz.

CMIP5. They are identified by the 21st century peak or stabilization of the radiative forcings (RF) derived from reference model (IPCC, 2013). We therefore had the lowest RCP scenario corresponding to a RF of 2.6 W m^{-2} by 2100; two medium RCP scenarios corresponding respectively to RF of 4.5 and 6 W m^{-2} by 2100 and the highest RCP scenario that corresponds to a RF of 8.5 W m^{-2} by 2100. Among all those scenarios, emissions would need to decline drastically in order to reach the level of 2.6 W/m² by the end of the century. According to Van Vuuren et al. (2011), to achieve that purpose, the cumulative emission reduction over the century will be about 70% compared to the baseline trends. This will need great efforts and involvement of every country in improving energy efficiency, replacement of unabated use of fossil fuels by renewable energy, nuclear power (Van Vuuren et al., 2011). As of today, both at national and international levels, little is done to achieve that purpose and even, countries among the big greenhouse gases emitters don't agree on actions to be taken forward to reduce emissions. The recent withdrawal of USA from the climate change agreements is an illustration of lack of consensus in that field. Therefore, achieving the purpose of the scenario of RCP 2.6 is not obvious. In this context, in predicting the distribution of *D. guineense*, we used two of the above scenarios: RCP 4.5 (the low medium) where some mitigation efforts by governments and world populations are supposed to limit RF at 4.5 W m^{-2} by 2100 and RCP 8.5 (the highest scenario) where mitigation efforts are supposed to be at their least. After selecting the most relevant variables, we ran MaxEnt with 10 replicates using the bootstrapping as replicated run type. In the bootstrapping replication process, the training data is selected by sampling with replacement from the presence points, with the number of samples equaling the total number of presence points (Phillips, 2010). This option will compensate the little numbers of presence points in parts of our LOI. Projection layers under each scenario were provided accordingly.

Model evaluation

We proceeded to the selection of models using threshold-independent tests. For this purpose, we took into account the Receiver Operating Characteristic (ROC) curve and its related Area Under Curve (AUC) (Phillips et al., 2006); for more model validation, we also used the Partial ROC test (Peterson et al. 2008; http://shiny.conabio.gob.mx:3838/nichetoolb2/). Furthermore, we used a threshold-dependent test (the True Skill Statistic (TSS) (Allouche et al., 2006); to appraise the decision thresholds we chose to classify MaxEnt outputs as unsuitable, suitable or highly suitable for the presence of the species in geographic space.

Impact of climate change evaluation

Using QGIS 2.16.2 adequate algorithms of the Geospatial Data Abstraction Library (GDAL), we reclassified, converted, and polygonize (raster to vector) appropriate output layers and calculated the extent of the spatial distribution of the species with respect to decision thresholds at present and in the future (horizon 2055) under the considered scenarios. The decision thresholds we used are "the minimum training presence" representing areas where ecological factors for the occurrence of *D. guineense* are as favorable as those found at the occurrence points (conservative and most ecologically reasonable option) (Pearson et al., 2007); the

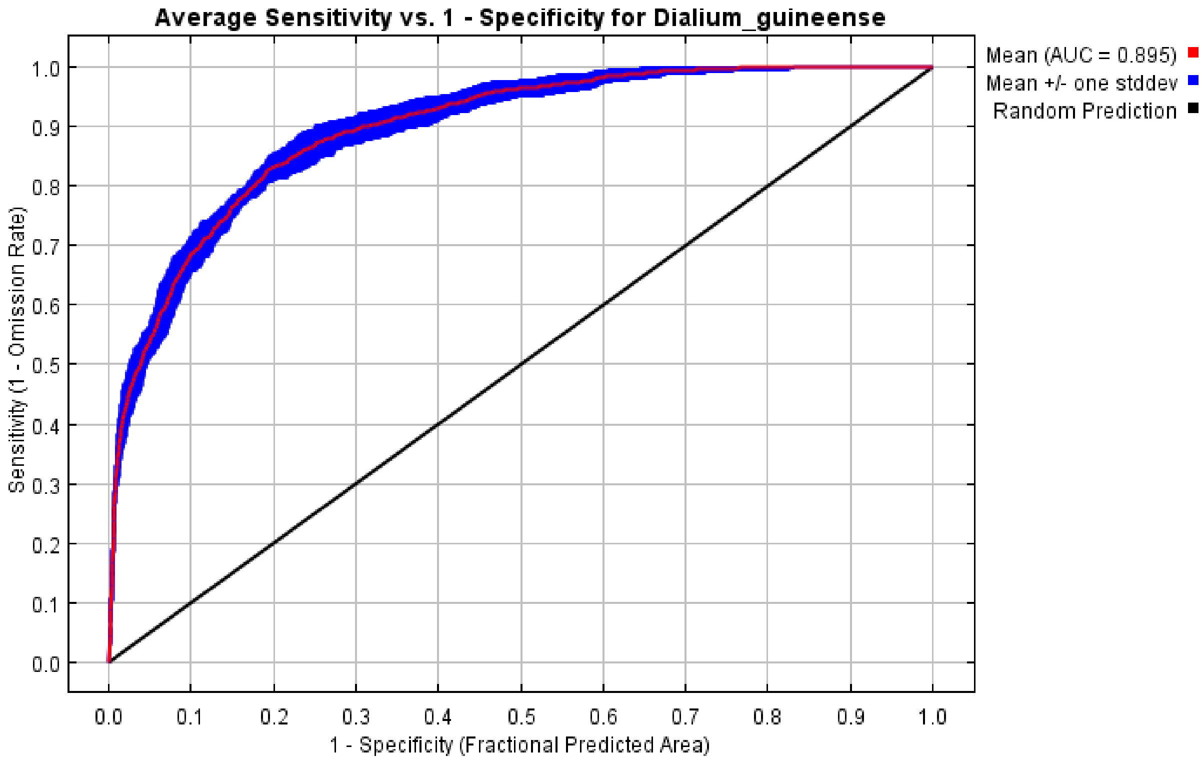

Figure 2. Average Receiver Operating Characteristic (ROC) and related Area Under Curve (AUC) of the 10 bootstrap replicates of the model retained.

maximum training sensitivity plus specificity (least conservative and most likely presence option). With respect to the decision thresholds, we categorized the whole distribution area of the species into a) stable area, that is the area suitable (pixels where the probability of presence of the species is more or equal to the logistic threshold related to the decision threshold considered) at present and predicted to be so in the future under either scenarios; b) unsuitable area (pixels where the probability of presence of the species is less than the logistic threshold related to the decision threshold considered) at present and predicted to remain so in the future under either scenarios; c) suitable area at present but predicted to be unsuitable in the future under either scenarios; d) unsuitable area at present but predicted to become suitable in the future under either scenarios. This helped us derive potential spatial distributions of *D. guineense* and use them as tools to inform the potential impact of climate change, which in turn allowed us suggesting strategies for the sustainable use and conservation of the species.

RESULTS

Model validation

The average training Area Under Curve (AUC) for the 10 bootstrap replicate runs was 0.895 with a standard deviation of 0.010 (Figure 2). This low value of the standard deviation indicates a limited dispersion of AUC values among the replicates. The results of Partial ROC test showed that after 500 simulations, the mean value for AUC ratio at 0.05 omission rate is 1.86 and that of AUC is 0.93. Furthermore, the test showed that the difference between the AUC from model prediction and the AUC at random is highly significant and therefore, the model performs better than random. The values of the True Skill Statistic (TSS) test at the threshold values of 0.043 (minimum training presence, conservative option) and 0.311 (maximum training sensitivity plus specificity, least conservative and most likely presence option) are respectively 0.288 and 0.586 and also showed that the model performed better than random.

Environmental variables controlling the spatial distribution of *D. guineense*

From our knowledge on the ecology of the species, *D. guineense* is a Guinean species, growing optimally in equatorial and subequatorial zones characterized by abundant and regular rainfall. Its presence in drier zones is usually linked to water galleries and swampy zones. The Jackknife tests of variable importance (Figures 3a, b, and c) and the table of variable contributions (Table 1) helped us identify four environmental variables as contributing most to the spatial distribution of *Dialium*

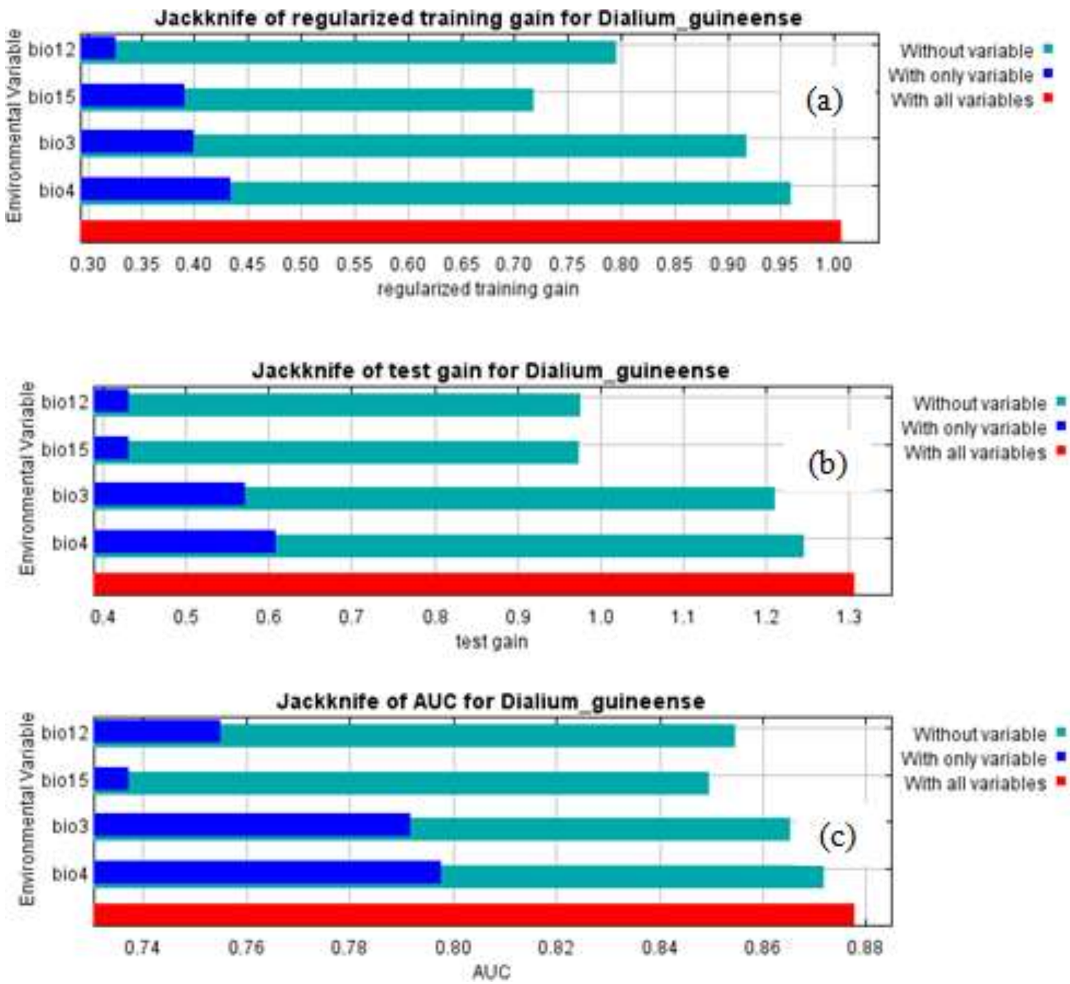

Figure 3. Jackknife tests of variable importance. a) with regularized training gain; b) with test gain; c) with AUC.

Table 1. Percentage contribution and permutation importance of the variables.

Variable	Percent contribution	Permutation importance
bio4	31.7	20.1
bio15	31.2	30
bio3	20.3	22.1
bio12	16.7	27.8

guineense. They are bio3 (isothermality), bio4 (temperature seasonality), bio12 (annual precipitation), and bio15 (precipitation seasonality). The Jackknife tests of variable importance showed that leaving out any of those four variables did not allow achieving the training gain, AUC and test gain levels of the whole set of variables. Consistent with the Jackknife tests, the table of variable importance (Table 1) showed that bio 4 (temperature seasonality) was the most important contributing variable to the model among the set of the four variables retained in the model. Bio 15 (precipitation seasonality) decreases the gain the most when omitted and appears to be the most informative variable of the model. The response curves of those variables to the suitability prediction of the species are in Figures 4a, b, c, and d. Bio3 clearly showed the responsiveness of the species to monthly diurnal temperature variability relative to that of the year. We deduced that the prediction of higher suitability for the species coincides with a percentage variation of about 62 to 75% of diurnal monthly range temperature relative to the annual one (Figure 4a). The species is therefore not linked to the extreme fluctuations of monthly diurnal temperature. The response curve of the species to bio4 (temperature seasonality) showed that the highest probabilities of its presence are linked to the least seasonality (1 to 15%) and that higher values are likely limiting its presence. The response curve of the species to bio 12 (annual precipitation) is also consistent with its ecology and

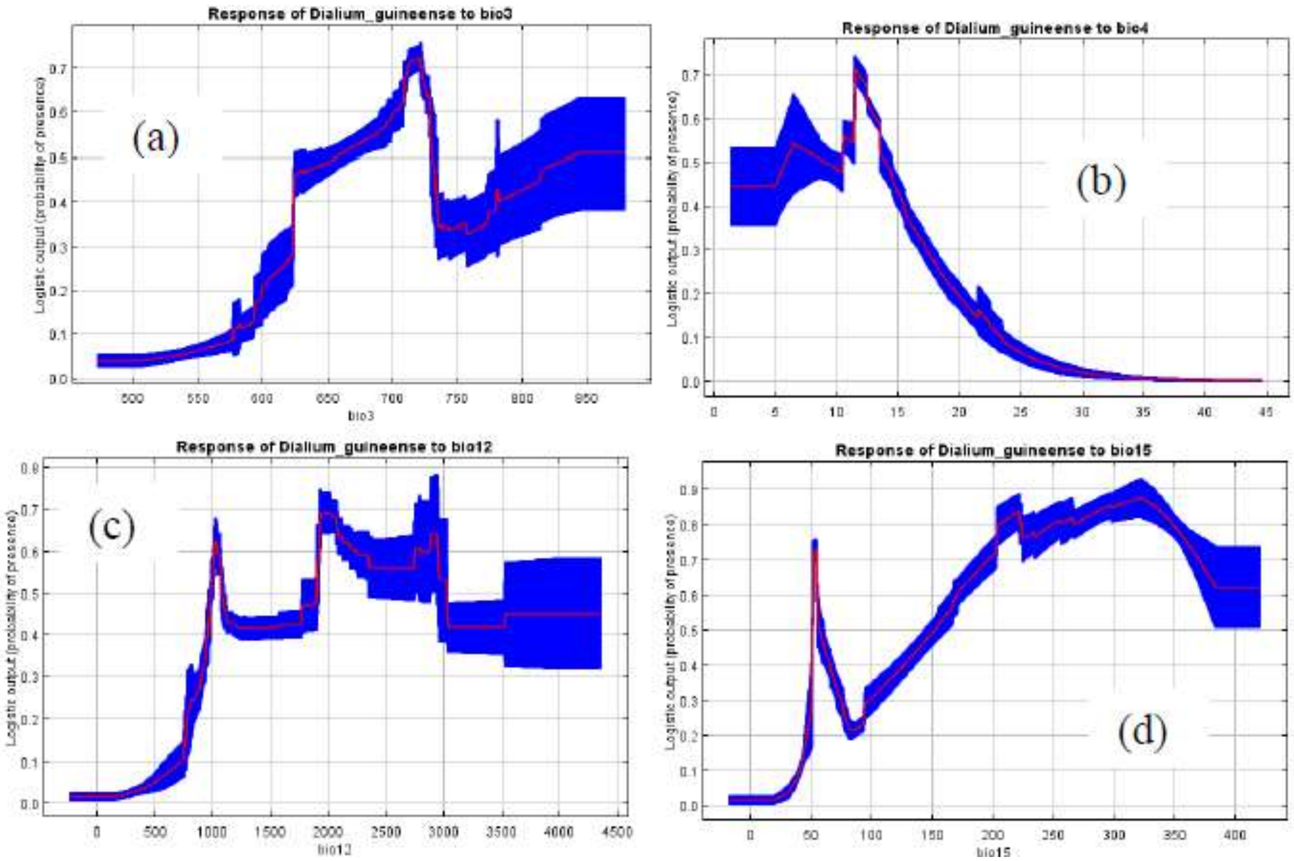

Figure 4. Response curves of most contributing variable.

indicated values of precipitation of 1000 mm and more as optimal values for the species high suitability prediction. The response of the species to bio15 (precipitation seasonality) showed that the prediction of highest suitability for the species is linked to the highest values (15 to 40%) of that variable. This result is also consistent with the known ecology of the species that is alternately exposed to dry and rainy seasons in its natural range.

Spatial distribution of the species at present

The present spatial distribution of *D. guineense* in the landscape of interest (LOI) is presented on Figure 5a. In the LOI, the prediction of suitability is higher southwards, mostly limited to coastal zones of West African countries. However, gaps of suitability (or low suitable areas) were predicted to occur all over the coastal zones. The northern parts of the LOI are the domain of unsuitable prediction, which may be related to the mostly dry Sahelian climate that is inconsistent with the ecology of the species. In Benin (Figure 5b), the distribution of the species is globally similar to that of the LOI. Consistent with the general distributions, we noticed that high suitability prediction is concentrated in the South of the country and more precisely in the six southern departments (Ouémé, Plateau, Littoral, Altlantique, Mono, and Kouffo) that are influenced by a subequatorial climate consistent with the ecology of the species. The suitability prediction is also noted in the central part of the country whereas the unsuitable prediction is mostly concentrated in the northern departments (Donga, Atakora, Borgou, and Alibori) mostly characterized by a Sudanian Sahelian climate, unsuitable for the ecology of *D. guineense*.

Projected distribution of the species in the future

The projected distributions of *D. guineense* for 2055 across the LOI are presented in Figures 6a and 7a, respectively under Africlim rcp 4.5 and rcp 8.5. Compared to the distribution at present (Figure 5a), we noted that the suitability prediction progressively decreases in most of the countries under both scenarios with a maximum decay under rcp 8 .5. In Benin (Figures 6b and 7b), consistent with the general predictions across the LOI, only the departments of Atlantique and Mono respectively in South Center and South West of the country, are

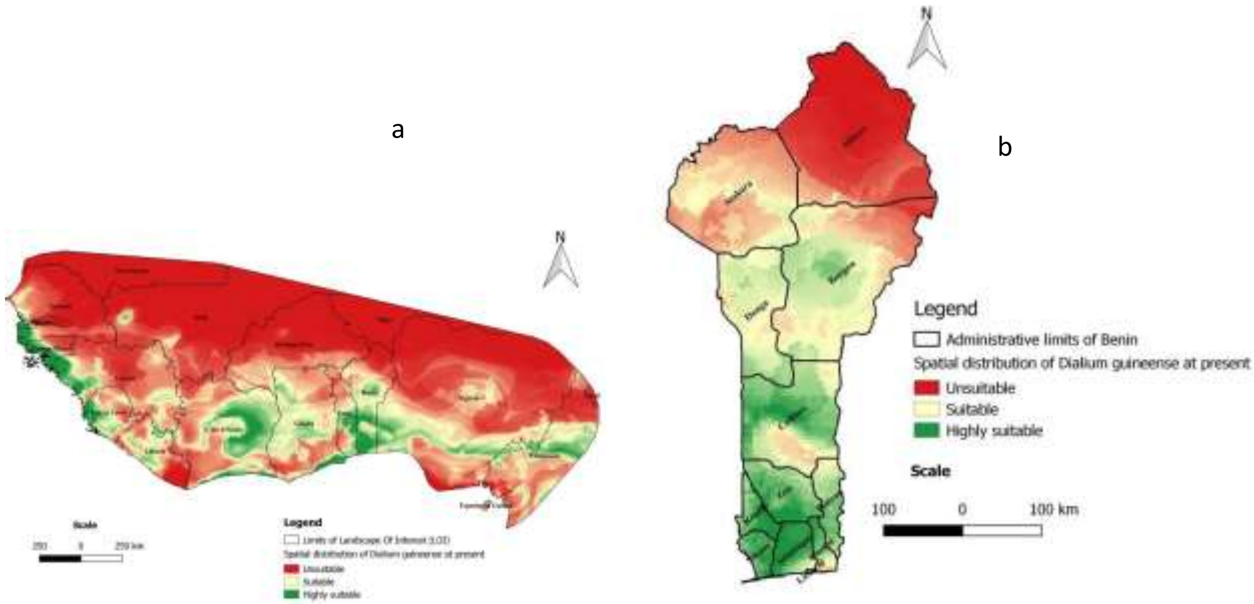

Figure 5. Spatial distribution of *Dialium guineense* at present: a) across the Landscape of Interest; b) across Benin.

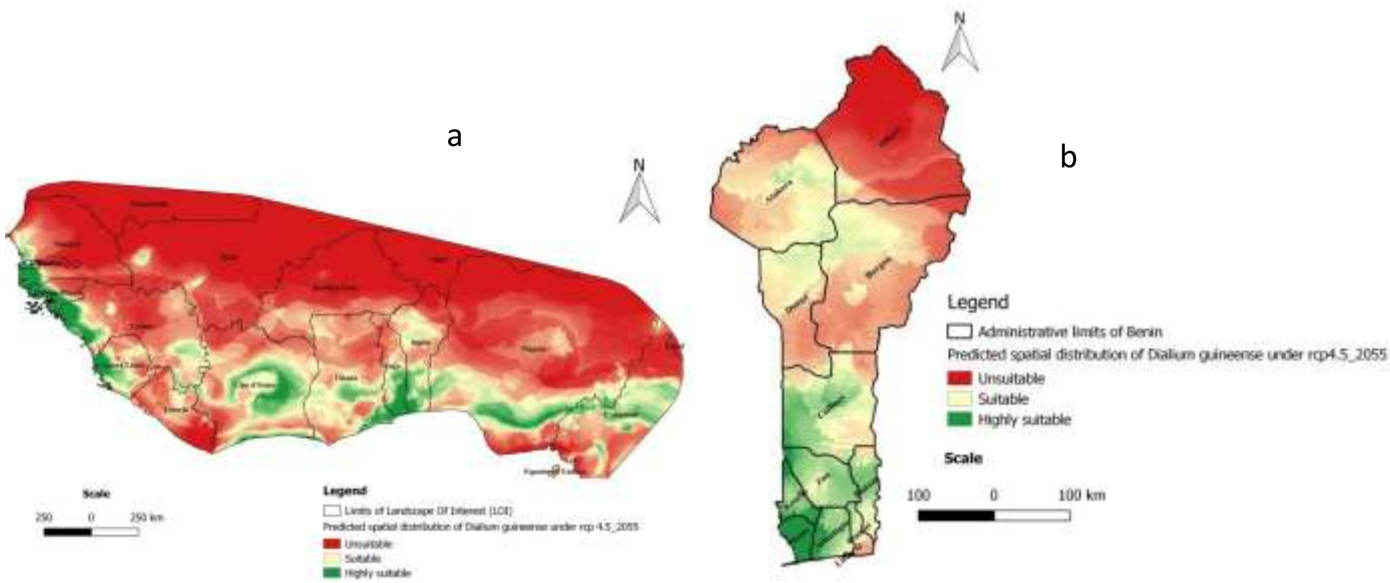

Figure 6. Predicted spatial distribution of *Dialium guineense* under Africlim RCP 4.5 horizon 2055: a) across theLandscape of Interest; b) across Benin.

predicted to remain suitable for the species under rcp 8.5.

Impact of climate change on the spatial distribution of *D. guineense*

We noted that under Africlim rcp 4.5 horizon 2055 (Figures 8 and 9; Tables 2 to 5), the predicted stable areas of the distribution of the species will be about 73% of the LOI when we considered the threshold of the minimum training presence and will decrease to 12% of the LOI when the threshold of the maximum training sensitivity plus specificity is considered. Under Africlim 8.5 horizon 2055, the corresponding values we noted for

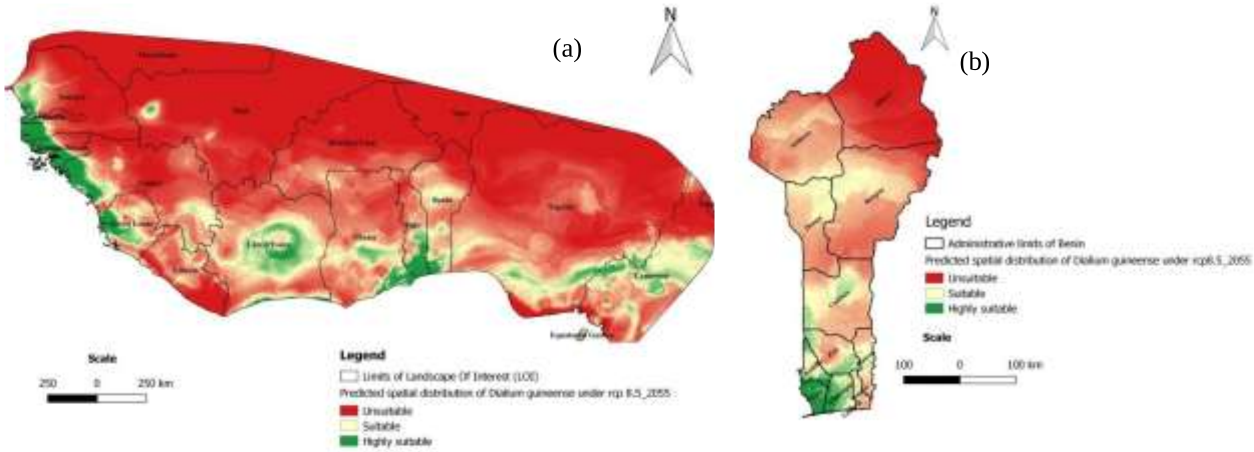

Figure 7. Predicted spatial distribution of *Dialium guineense* under Africlim RCP8.5 horizon 2055: a) across the Landscape of Interest; b) across Benin.

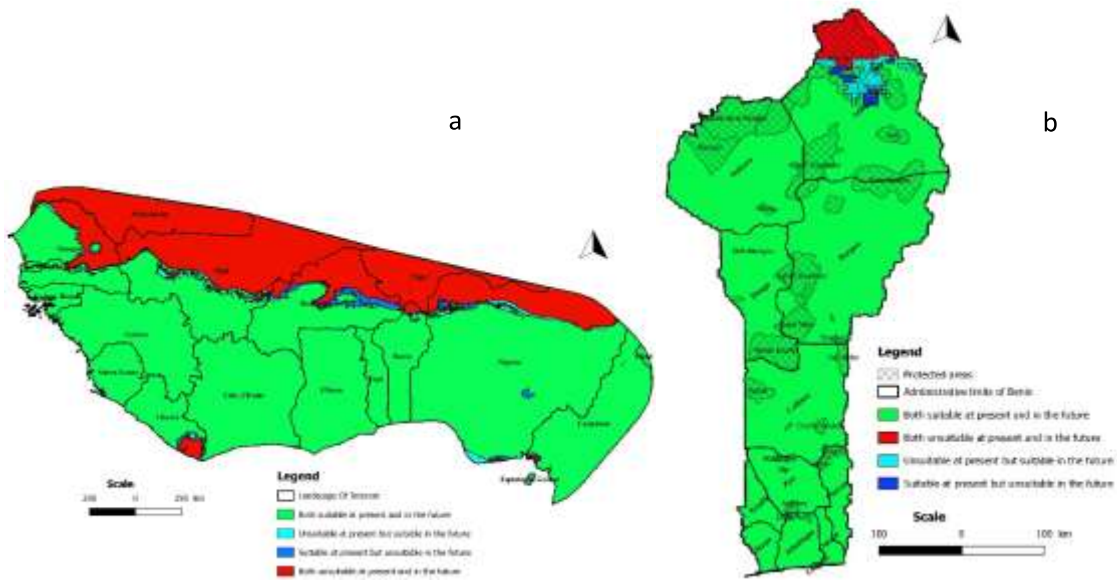

Figure 8. Impact of climate change on *Dialium guineense* at the threshold of minimum training presence under Africlim RCP4.5, horizon 2055: a) across the Landscape of Interest; b) across Benin.

the stable areas are respectively 70 and 8% of the LOI (Figures 10 and 11; Tables 2 to 5). Globally, under Africlim rcp 4.5 at horizon 2055 (Figures 8 and 9; Tables 2 to 5) the predicted suitable areas for the distribution of *D. guineense* will be about 74% of the LOI at the threshold of the minimum training presence and will decrease to about 17% of the LOI at the threshold of the maximum training sensitivity plus specificity. Under Africlim 8.5 horizon 2055, the corresponding values of the predicted suitable area for the distribution of *D. guineense* will be respectively 70 and 11% of the LOI (Figures 10 and 11; Tables 2 to 5). At the threshold of the minimum training presence, under Africlim 4.5, horizon 2055, the predicted suitable areas of *D. guineense* is mostly concentrated on coastal countries with however a thorough extension northwards except a South Eastern part of Liberia at the border of Côte- d'Ivoire. Only the upmost northern parts coinciding with the Sahelian zones of the LOI are predicted unsuitable for the species. At the same threshold, under Africlim rcp 8.5, horizon 2055, the predicted suitable areas of the distribution of the species is close to its extension under Africlim rcp 4.5 with

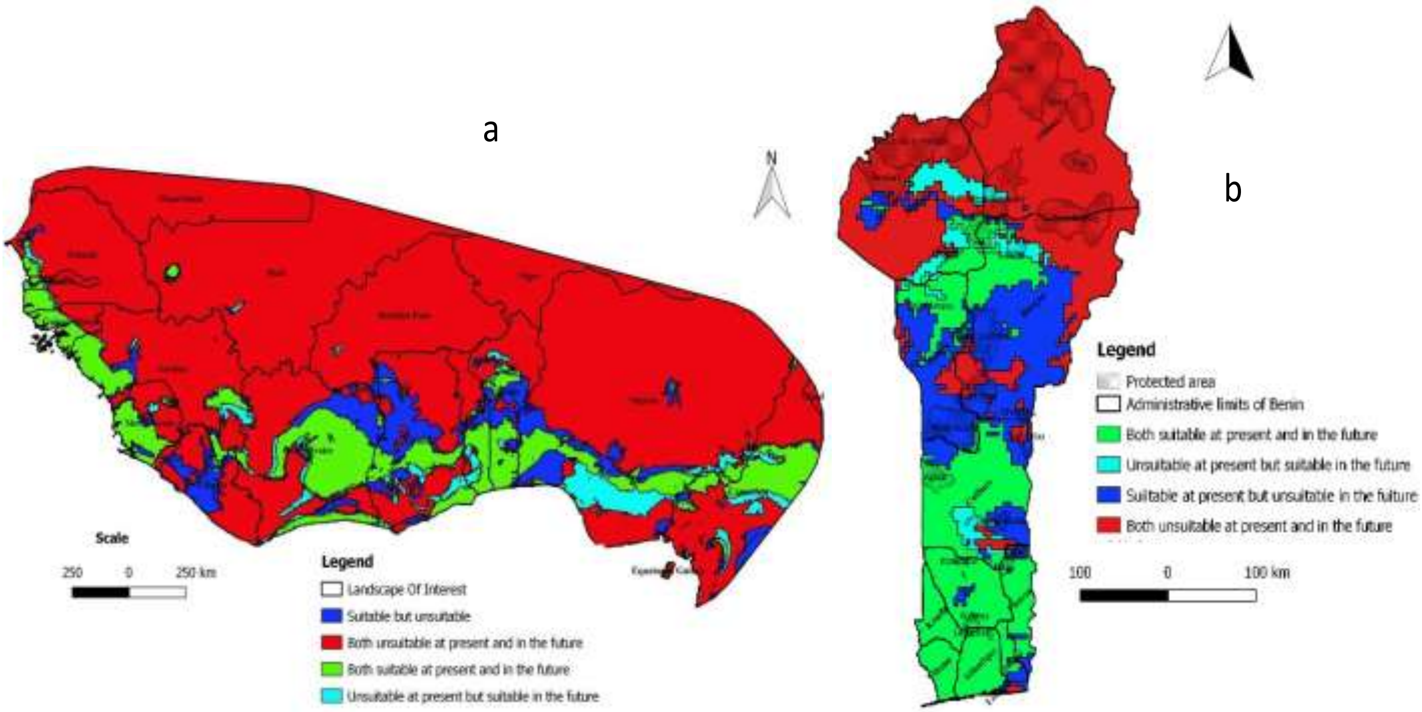

Figure 9. Impact of climate change on *Dialium guineense* at a more liberal threshold maximum training sensitivity plus specificity under Africlim RCP4.5, horizon 2055: a) across the Landscape of Interest; b) across Benin.

Table 2. Impact of climate change across the landscape of Interest at the threshold of the minimum training presence.

Status of spatial distribution	RCP 4.5		RCP 8.5	
	Area (km²)	Percentage (%)	Area (km²)	Percentage (%)
Both suitable	2586571,09	72,69	2480447,96	69,71
unsuitable at present but suitable in the future	40409,30	1,14	23945,64	0,67
Subtotal	***2626980,39***	***73,83***	***2504393,6***	***70,38***
Both unsuitable	883892,02	24,84	900355,72	25,30
Suitable at present but unsuitable in the future	47291,79	1,33	153414,89	4,31
Subtotal	***931183,81***	***26,17***	***1053770,6***	***29,62***
Total	**3558164,2**	**100**	**3558164,2**	**100**

Table 3. Impact of climate change across Benin at the threshold of the minimum training presence.

Status of spatial distribution	RCP 4.5		RCP 8.5	
	Area (Km²)	Percentage (%)	Area (Km²)	Percentage (%)
Both suitable	106163,20	94,28	103571,95	91,98
unsuitable at present but suitable in the future	1773,71	1,58	305,70	0,27
Subtotal	***107936,91***	***95,86***	***103877,65***	***92,25***
Both unsuitable	4051,28	3,60	5519,29	4,90
Suitable at present but unsuitable in the future	611,81	0,54	3203,07	2,84
Subtotal	***4663,09***	***4,14***	***8722,36***	***7,75***
Total	**112600**	**100**	**112600**	**100**

Table 4. Impact of climate change across the landscape of Interest at the liberal threshold of maximum training sensitivity plus specificity.

Status of spatial distribution	RCP 4.5		RCP 8.5	
	Area (Km²)	Percentage (%)	Area (Km²)	Percentage (%)
Both highly suitable	421500,59	11,85	281694,02	7,92
Not highly suitable at present but suitable in the fuute	171466,05	4,82	117623,25	3,31
Subtotal	***592966,63***	***16,66***	***399317,27***	***11,22***
Both highly unsuitable	2751656,24	77,33	2850265,46	80,10
Highly suitable at present but unsuitable in the future	213541,33	6,00	308581,47	8,67
Subtotal	***2965197,57***	***83,34***	***3158846,93***	***88,78***
Total	**3558164,20**	**100,00**	**3558164,20**	**100,00**

Table 5. Impact of climate change across Benin at the liberal threshold of maximum training sensitivity plus specificity.

Status of spatial distribution	RCP 4.5		RCP 8.5	
	Area (Km²)	Percentage (%)	Area (Km²)	Percentage (%)
Both highly suitable	31345.55	27.84	15625.79	13.88
Not highly suitable at present but suitable in the fuute	6352.68	5.64	943.29	0.84
Subtotal	***37698.23***	***33.48***	***16569.08***	***14.72***
Both highly unsuitable	52025.31	46.20	61600.84	54.71
Highly suitable at present but unsuitable in the future	22876.46	20.32	34430.08	30.57
Subtotal	***74901.77***	***66.52***	***96030.92***	***85.28***
Total	**112600**	**100**	**112600**	**100**

however a remarkable reduction at the northern parts of the LOI. At the threshold of the maximum sensitivity plus specificity, only portions of some coastal countries are predicted suitable to the species and this distribution worsted up under Africlim 8.5, horizon 2055 (Figures 8 to 11; Tables 2 to 5).

In Benin, the predictions are globally similar to the general trends of the LOI though, some particularities are noted. At the threshold of minimum training presence, only an upmost northern part of the country (4663 Km², 4% of the country) covering the national park W in the Department of Albori is predicted unsuitable for the species under Africlim 4.5 horizon 2055 (Figure 8a and Table 3). Under Africlim 8.5 horizon 2055, the predicted unsuitable area of the distribution of the species extended southwards (87722 Km², 7.75% of the country) and encompassed the forest reserves of Djona and Alibori (Figure 10b, Table 3). At the threshold of maximum training sensitivity and specificity, the predicted suitable area of the species is about 33% of the total area of the country (112600 Km²) under rcp 4.5 horizon 2055 (Figure 9b; Table 5) and will decrease by more than 50% under rcp 8.5 at the same horizon (Figure 11b, Table 5). Moreover at that threshold, when we focused on Benin under rcp 4.5 at horizon 2055 (Figure 9b), we realized that only few protected areas, namely the forests of Djigbé in the Department of Atlantique in South Benin, Lama in South and Center Benin, Kétou-Dogo in the Department of Plateau (South East Benin), Agrimey, Dan, Atchérigbé at the Center part of the country in the Department of Zou, and Agoua forest in the Department of Collines (Center northern part of Benin) are globally predicted to be suitable for the distribution of the species. The remaining protected areas, particularly those of the North of the country are predicted to be unsuitable for the distribution of the species. Under rcp 8.5 at the same horizon of 2055 (Figure 11b), only Djigbé, Lama, and Agrimey forests will remain suitable for the distribution of the species.

DISCUSSION

Consistency of the environmental variables controlling the spatial distribution of *D. guineense* with regards to the ecology of the species

D. guineense grows in Sub Saharan Africa (Orwa et al., 2009; Ayessou et al., 2014) in humid dense forests, dry dense forests, and forest galleries (Ewédjè and Tandjiékpon, 2011). In its natural range, the species is submitted to a temperature ranging from 25 to 32°C and a mean annual rainfall of 900 to 3000 mm (Ewédjè and Tandjiékpon, 2011). In dry zones, its occurrence is

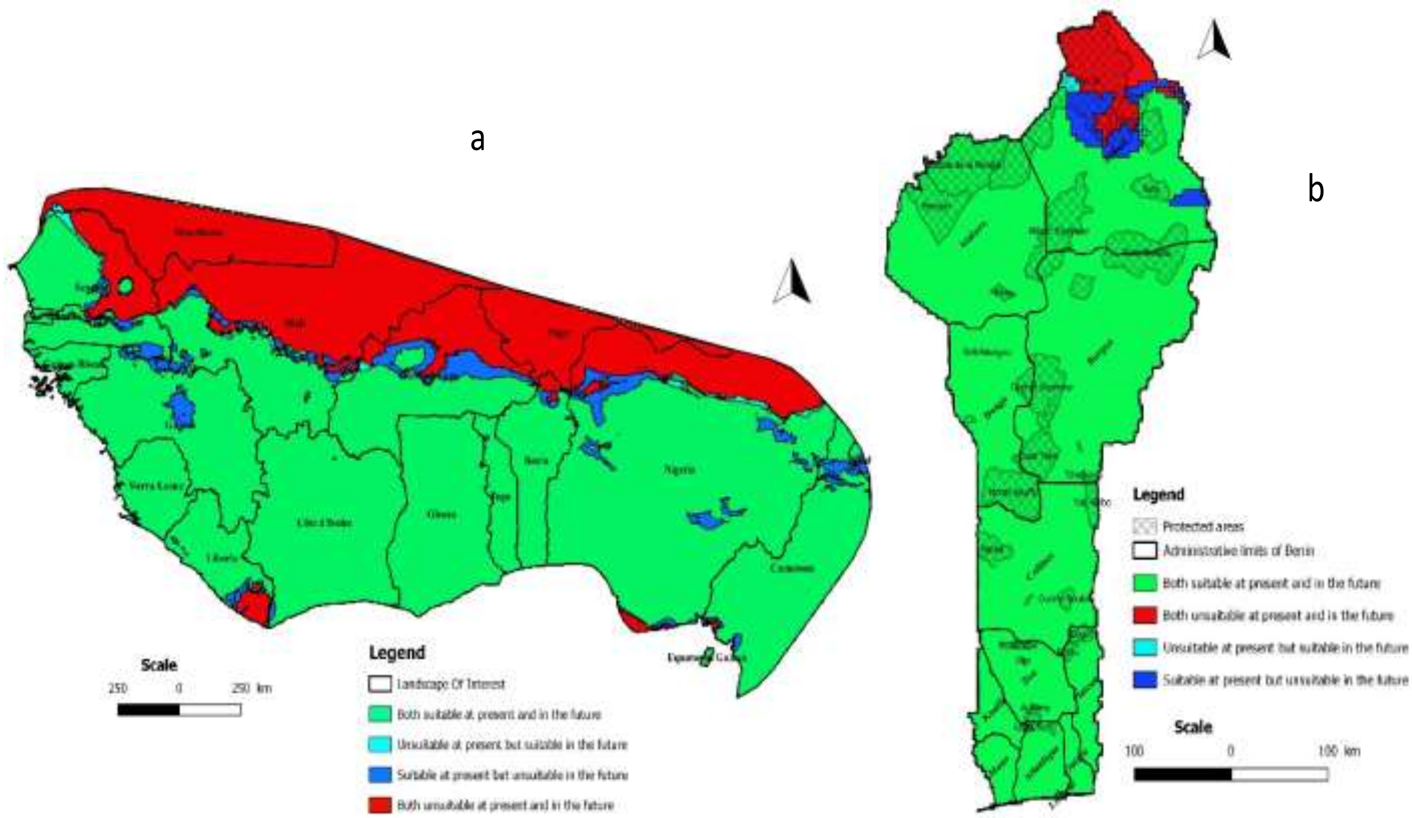

Figure 10. Impact of climate change on *D. guineense* at the threshold of minimum training presence under Africlim RCP8.5, horizon 2055: a) across the Landscape of Interest; b) across Benin.

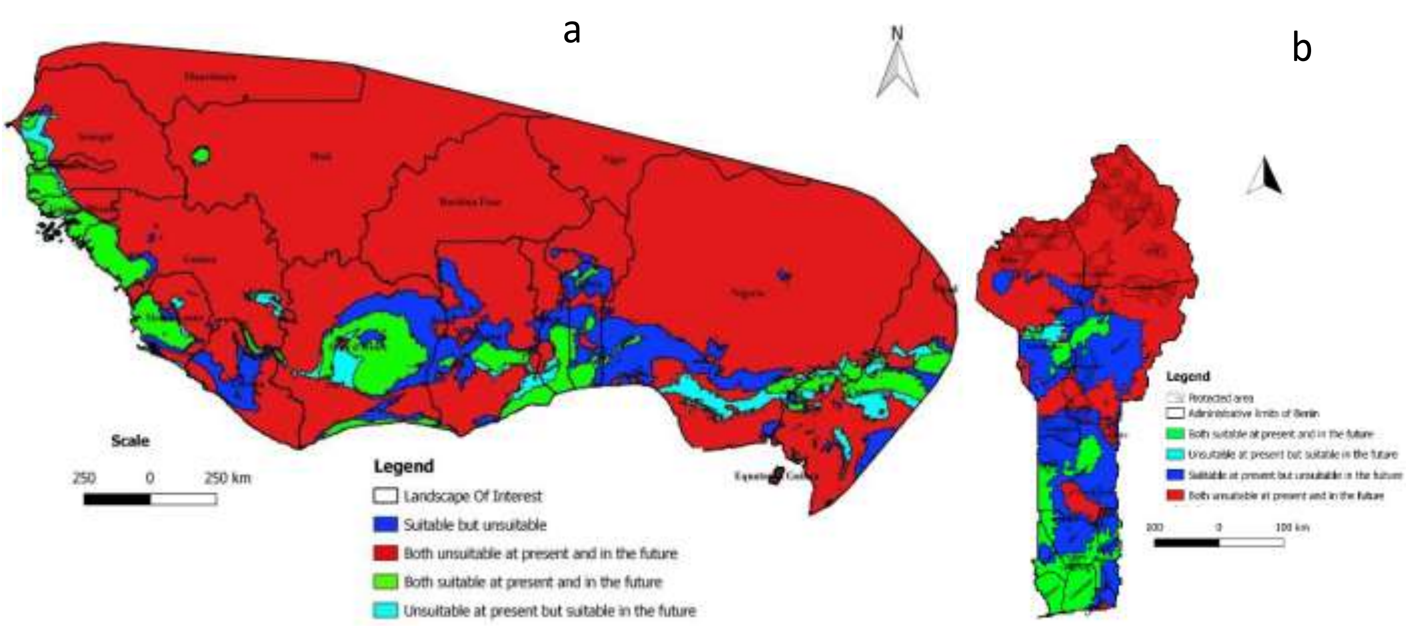

Figure 11. Impact of climate change on *D. guineense* at a more liberal threshold (maximum training sensitivity plus specificity) under Africlim RCP8.5, horizon 2055: a) across the Landscape of Interest; b) across Benin.

always linked to waterways and swampy zones. Our findings are therefore reliable with regards to the ecology of the species. Indeed, the annual precipitation (bio 12) and its seasonality (bio 15) are among the most contributing variables to the prediction model of the spatial distribution of the species. Precipitation seasonality (bio 15) is a measure of the variation in monthly precipitations over the course of the year (O'Donnell and Ignizio, 2012). Our results showed that the highest probabilities (>0.5) for the presence of the species are obtained between 15 and 40% of bio 15 avoiding then the extreme variations of precipitation. Water has many functions in the plants and is found to impact the distribution patterns of species at finer scales (Willis and Whittaker, 2002) as compared to global scales. It is a solvent for mineral nutrients and the complex organic matters produced within the plant; it also acts as a temperature regulator during the process of plant transpiration and serves as raw material in the process of photosynthesis which is the basic process underlying all life (Ferguson, 1959). Plants can be stressed by lack of moisture as well as an excess of moisture (Haferkamp, 1987). Because of those important functions, the presence of water in the environment of plants is quite important. It is therefore understandable that large variations in water supply, that is high values (> 40) of bio 15, can limit the growth and therefore the presence and extension of *D. guineense*. Our results are supported by many others. Indeed, high values of bio 15 can be associated with drought or water deficit. Drought is the most significant environmental stress in agriculture worldwide. Drought induces water deficit that is known to be harmful for plants and cause among others, a decline in stem elongation, reduction in photosynthetic performance and then reduce plant growth, development, survival and productivity (Boyer, 1982; Cattivelli et al., 2008; Ings et al., 2013). Although *D. guineense* is found in dry areas (Sudanian Sahelian regions) along waterways or in swampy areas, in its natural range (Guinean regions), the species grows on well drained soils and is alternatively submitted to dry and rainy seasons. Low values of bio 15 (<5%) are associated with little variation in water supply. We can therefore understand that in the natural range of *D. guineense*, constant water supply or little water supply variation (low values of bio 15 (<5%)) can affect the species' physiology and therefore limit the presence of a non-hydrophilic or non- hygrophilous plant species like *D. guineense*.

Although annual mean temperature (bio 1) was not among the most important contributors to the distribution model of *D. guineense*, its variations in terms of isothermality (bio 3) and temperature seasonality (bio 4) proved to significantly control the spatial distribution of the species. It is useful to underline here that the rate of plant growth and development is controlled by its surrounding temperature and each plant has a specific temperature range characterized by a minimum, maximum and optimum (Hatfield and Prueger, 2015). Isothermality (bio 3) quantifies how large the day to night temperatures oscillate relative to annual oscillations (O'Donnell and Ignizio, 2012) and the highest probabilities (>0.5) of our modeled species' presence was achieved with values of bio 3 between 65 to 75% (mean to high values of the parameter). The temperature seasonality (bio 4) is the amount of temperature variation over a given year based on the standard deviation of monthly temperature averages (O'Donnell and Ignizio, 2012). The highest probabilities (>0.5) of our species' presence was achieved with values of bio 4 between 5 to 15% (small variations of temperature). According to Hatfield and Prueger (2015), vegetative development increases as temperature rises to the species optimum level and for most plant species vegetative development usually has a higher optimum rate than for the reproductive development. In light of their findings we can understand that large variations of temperature (high value of bio 4) can affect the optimum temperature of *D. guineense* and then impact its distribution and development both at vegetative and reproductive phases. We therefore deduce that the maximum value of bio 4 beyond which the distribution of *D. guineense* can be negatively impacted is 15%. The rate of daily temperature variation relative to the annual oscillation (bio 3) must be less relevant for plant growth and development than temperature variation along the year (bio 4) and this can explain the relative tolerance of *D. guineense* displaying its maximum presence probabilities between 65 to 75% (mean to high values) of bio 3. The generalization of a model depends on the choice of the variables used to run it (Elith et al., 2011). In our case, the variables bio 3 and bio 4 measured availability and variability of light and heat to the species while bio 12 and bio 15 measured respectively the availability and variability of water for *D. guineense*. As those variables controlling the spatial distribution of the species are fundamental primary conditions, our model can be generalized to regions outside the study areas and serve the purpose of species management in such regions (Elith et al., 2011).

Impact of climate change on the distribution of the species with regards to the decision thresholds

As pointed out by Pearson et al. (2007), we understand that niche modeling to estimate the impact of climate change on species depends both on environmental factors taken into account when building the models and the thresholds used to interpret the outputs. The outputs must therefore be interpreted with caution. At the threshold of minimum training presence, the impact of climate change on *D. guineense* is at its minimal since more than 70% of our LOI and more than 90% of Benin will remain suitable for the distribution of the species under rcp 4.5 and 8.5 at horizon 2055. In contrast, when we considered the least conservative option at the threshold of maximum training sensitivity plus specificity, the suitable area for the distribution of the species sharply decreased to 17 and 34% respectively in the LOI and in Benin under rcp 4.5 and to 11 and 15% respectively in the LOI and in Benin under rcp 8.5. Our findings therefore confirmed that the choice of decision thresholds greatly matters. When we considered the impact of climate change on other species, we found that *Lantana camara* is projected to cover 65% of the Pendjari Biosphere reserve in Benin and about 6% of the W National Park (Fandohan et al., 2015). As this projection will remain so in the future (Fandohan et al., 2015), under rcp 8.5 and at the liberal threshold of maximum training sensitivity plus specificity, *D. guineense* will be more threatened by climate change than *Lantana camara* at least in the northern protected areas of the country. Likewise, the seven species studied by Adjahossou et al. (2016), *Afzelia Africana, Prosopis africana, Khaya senegalensis, Detarium microcarpum, Anogeissus leiocarpa, Burkea Africana,* and *Daniellia oliveri,* are predicted to have globally suitable areas for their cultivation and conservation in North Benin at the threshold of 10 percentile training presence. Therefore they appear to be less threatened than *D. guineense* in the North of the country at the liberal threshold of maximum training sensitivity plus specificity under rcp 8.5 horizons 2055. Furthermore, under the threshold of minimum training presence, *Dialium guineense* will be less threatened than *Lonchocaprus serinaceus* and *Anogeissus leiocarpa* across Benin (Gbètoho et al., 2017) both under rcp 4.5 and rcp 8.5 horizons 2055. In contrast however, under the threshold of maximum training sensitivity plus specificity, *D. guineense* will be more threatened than *Lonchocaprus serinaceus* and *Anogeissus leiocarpa* across Benin under both scenarios at horizon 2055 (Gbètoho et al., 2017). The advantage of the threshold of minimum training presence, the most conservative option, is that it has a direct ecological interpretation, in identifying sites that are at least as suitable as those where a species' presence has been recorded (Pearson et al., 2007). In contrast, the threshold of maximum training sensitivity plus specificity is a more liberal, yet least conservative but most likely presence option. This latter threshold, as shown by our results, is less explorative and therefore less appropriate to identify the maximum of the potential areas of the distribution of the species. As MaxEnt is known to have a high predictive ability (Pearson et al., 2007) we inferred that our results at the threshold of minimum training presence showed the largest potential spatial distribution of the species in the future.

Considerations on the strategies of the conservation and sustainable use of *D. guineense*

In our model building, we considered only environmental factors. Doing so has some limitations and uncertainty (Abrahms, 2017) in predicting species distribution. Indeed, ecological niche models predict the environmental space that corresponds to the fundamental niche of the species (Soberón and Peterson, 2005). It can yield both false positives and false negatives in the presence of the species in the predicted geographic areas (Thuiller et al., 2005). False positives occur when other factors than climate control the distribution of the species and prevent it from growing in the potential area considered (Thuiller et al., 2005; Blach-Overgaard et al., 2010), whereas false negatives appear when lack of information in the background sample or incomplete sampling efforts prevent from accurately predicting the presence of the species. Implicitly, those other factors not associated with climate, can be related to biotic interactions and accessibility (that is dispersal capacity) of the species to reach geographic areas presenting conditions of its fundamental niche (Soberon and Peterson, 2005) and thus impacting the distribution of the species although it is well known that at very broad continental and global scales, climate is the most important factor to predict the distribution of species (Woodward, 1987; Willis and Whittaker, 2002; Thuiler et al., 2005; Blach-Overgaard et al., 2010).

Another factor to be considered is human pressure as a consequence of demography explosion. For decades, Benin is losing about 50,000 ha of forest every year (FAO, 2015) due to human pressure and therefore the depletion of *D. guineense*, a multipurpose species, from its suitable areas is common at least in the South of the country. This contributes to increase the false positives in the prediction of our models. Therefore, our results under both scenarios illustrated the possible distribution of the species from an optimistic and explorative option at the threshold of minimum training presence to a more pessimistic, yet more likely presence but least explorative option at the threshold of maximum training presence plus specificity. We agree here with Pearson et al. (2007) that the choice of a decision threshold should depend on proposed application of the models. In order to conserve *D. guineense* with respect to the impacts of climate change, we recommend a more conservative and explorative option that consists in considering the distribution of species under both scenarios but at the threshold of minimum training presence. Some actions can therefore be undertaken. First, we recommend a field inventory in the predicted suitable areas of the species to find out where the species is actually absent or present at low densities (for example less than 10 trees / ha). Second, we recommend that forest administration and its related offices grow the species in nurseries and introduce it in the areas previously identified as of low densities or absence of the species; in such areas, after planting, tending operations (weeding, liana cuttings, thinning…) should be carried out by forest administration to ensure the survival of *D. guineense* along the successional stages of the vegetation growth. Third, because the species is well appreciated by populations and to lighten pressure on it, we recommend capacity building of populations to raise their ability in growing the species in nurseries, and in planting and tending operations on the field or home gardens. Fourth and more globally, forest administration can organize workshops to raise the awareness of populations on the issues of threats to biodiversity and the adequate behaviors compatible with its conservation. Fifth, we also recommend an adaptive approach to the conservation of the species (Williams and Brown, 2012) that will consist in evaluating in the coming future possible new trends in the evolution of its population's traits (densities, regeneration processes, survival, growth through developmental stages of vegetation) and the environmental or non-environmental factors involved in such evolution so as to develop new strategies and actions to a more effective conservation of the species with time.

Conclusion

Our study revealed that, consistent with its ecology, the spatial distribution of *D. guineense*, a Guinean species is controlled by four environmental variables bio3 (isothermality), bio4 (temperature seasonality), bio12 (annual precipitation), and bio15 (precipitation seasonality). At present the prediction of suitable area of the species in West Africa is higher southwards, mostly limited to coastal zones with however some gaps of occurrence all over its spatial distribution. Climate will impact the spatial distribution of the species because the suitability prediction will progressively decrease in most of the countries of our study area under both scenarios with a maximum decay under rcp 8 .5. We need therefore to apply adaptive strategies to conserve the species. We then suggest that the species be planted in the predicted suitable areas to account for insufficient existing densities or absence of the species. Populations should also be trained so as to be capacitated to grow, plant and carry out tending operations on the species.

As future investigation, since a species does not grow alone on the field, it will be useful to find out, how plant communities including *D. guineense* can be resilient to the climate and global changes in the future.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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Quantifying of plant species diversity, composition and density at Dammam Region, Eastern province, Saudi Arabia

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This study assessed the diversity composition and density of plant species at Dammam Region, Eastern Province, Saudi Arabia. Plant diversity is a vital component of any ecosystem. It is a well-known fact that, worldwide, thousands of plant species are endangered and facing extinction with the current trend of their influence and destruction. Changes in the structure of the assortment of resources lessen plant community's opportunity to respond to new problems and occasions. Plant diversity is facing danger of new plant diseases or pests, species extinction, climatic changes and other obstructions. A survey of 12 different sites was done and botanic biodiversity was evaluated. The plant diversity was evaluated by applying different methods namely: relative abundance index, species richness D* index and Shannon-Weaver index. It is clear that many plant species and habitats of Dammam area are subjected to severe disturbance due to new constructions without environmental impact assessment.

Key words: Biodiversity, biodiversity measures, endangered species, relative abundance index, species richness D*, Shannon-Weaver index.

INTRODUCTION

In the last three decades, there is a massive development in construction and industrial activities at Saudi Arabia. More or less parallel to national development, there is a growing awareness concerning the impact of temperature rise, industrialization, desertification and shift in the growing seasons of plants, loss of pollinators and seed dispersers, and increasing frequency of forceful weather events such as drought, storms and floods, making several valuable plants to be extinct (Bapat et al., 2012; Gardener et al., 2009). According to the International Union of Conservation of Nature (IUCN 1980), it is estimated that the current species extinction rate is between 1000 and 10,000 times higher than it would naturally be. It is acknowledged that the future survival of humanity depends on the conservation and protection of natural wealth, and destruction of a species or a genetic line symbolizes the loss of a unique resource. This type of genetic and

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(A) (B)

Figure 1. (A) Map of the study area illustrating the sampling sites. **(B)** Satellite map of Arabian Gulf, Saudi Arabia, showing the study areas.

environmental deprivation is irreversible (Poi, 2011). The single most important botanical task in eco-civilization construction is the conservation of plant species with their genetic diversity (Hamilton et al., 2017). The environmental factors affect the plant species composition and the establishment and stability of seedlings. Furthermore, the interactions of environmental factors are important in the restoration process and must be considered in the management of the areas (Gattie et al., 2003).

In fact, there is no doubt that plants grow naturally in different environments and are exposed in these environments with a range of climatic factors that suit their growth and sometimes exceed conditions that are not commensurate with their requirements for growth. Soil types with different structure and nutrients are important for plant growth and community development. Although, 95% of experimental studies support a positive relationship between diversity and ecosystem functioning, many have found that only 20 to 25% of species are needed to maintain most biogeographically ecosystem processes (Schwartz et al., 2000).

Rahman et al. (2004) investigated the medicinal plant diversity in the flora of the Kingdom of Saudi Arabia; this communication emphasizes the importance of setting up conservation priorities, and sustained development of various medicinal plants of Saudi Arabia. Saudi Arabia has a hot desert climate and rainfall is scarce in most parts of the country. The diversity of the flora of Saudi Arabia as well as other countries in the peninsula has received less attention for a long time due to its arid climate. The climatic and anthropogenic factors are the most vital factors affecting plant species distribution and abundance (Emad and El-Ghazali, 2013; Kaky and Gilbert, 2016, El-Shabasy, 2016).

In the current study, different measures of plant diversity are introduced with an effective indicator of underlying feature diversity. Phylogenetic diversity will be viewed based on cladistics relation among any group of taxa, not just species (Faith, 1992; Alfarhan, 1999). Regarding conservation priorities, the measurements developed in the present study was initially intended for application on species, population and ecosystem levels. However, since it is not an easy task, the study of plant diversity with time over specific place is highly required. The purpose of the present study is to shed light on assessment of plant species diversity, composition and density at Dammam Region, Eastern province of Saudi Arabia. Plant resources are a vital measure of a country's wealth. Its unsustainable use can lead to irreversible/permanent destruction to the ecosystems.

MATERIALS AND METHODS

Study area

This study is conducted at Dammam city and varsities with an area of about 800 km^2. Dammam is a city found in Eastern Province, Saudi Arabia. It is located at 26.43° Latitude and 50.10° Longitude and it is situated at elevation of 10 m above sea level. The studied site is illustrated in Figure 1. Geomorphologically, Dammam Region is characterized by its low surface with gradual elevation towards north and lake of Wadies. It lies within the Central coastal lowland subregion of Eastern costal region.

Climatically, the study area is classified as an arid to extremely arid region (UNESCO, 1977). The mean annual rainfall is 6.6 mm. The dominant temperature fluctuates between mean minimum of 10.2°C and mean maximum of 44.6°C.

Collection of data

Several field trips were done in and 12 sites were investigated (Tables 2 and 3). In each site, the plant species are listed by evaluating several parameters. The collected plant specimens were identified and named according to Mandaville (1990), Migahaid (1996) and Chaudhary (1999, 2000, 2001). Calculations of various vegetative parameters are according to Magurran (2003).

Field study

In addition to determination of the community type, plant covers, number of individuals per m^2 for each species, also, phenology and soil feature are recognized. All sites were documented with different photos and by GPS.

Samples of obscure plant species were collected, pressed and preserved on paper sheets for full identification. Some soil samples were collected to compare habitat features of plants common in different localities. Twelve soil samples were collected, covering different plant communities and habitats.

Field visits were repeated to the study area to investigate communities and plant species and make the following measurements:

1. A list of the plants "with complete scientific identification", with a case study of each species, growth aspects and phonological features.
2. Species richness of the vegetation in studied sites were calculated as the average number of species per stand, and species index D* turn-over as the ratio between the total number of species in the sample (N) and the number of species (S):

Species richness index D* = (S - 1)/Log N

3. Relative abundance index" Ra" was calculated; Ra = N × 100/N, where N is the number of a species and Ns is the total numbers of all individuals. The results are categorized according the following scale: Dominant species = >70%, abundant spp. = 40 to 70%, frequent = 10 to 40% and rare spp. = <10%
4. Relative evenness "H" of species are calculated using Shannon-Weaver (Pielou, 1975), on the basis of the relative cover of species.

$$H = - \sum Pi \times LnPi$$

Soil analysis

Soil samples were collected at 3 random points from each site as a profile (composite samples) from two depths: surface layer 0-5cm and active absorbing layer 5-30cm depth. Soluble chlorides were determined by precipitation by AgCl and titration, also, sulphates and ammonia (ppm) were precipitated gravimetrically and estimated according to A.O.A.C (1998). Major cations such as sodium, potassium, calcium and magnesium are determined in the 1:5 soil extract by flame photometer (Jones, 2001) and their concentrations are expressed in mg kg^{-1} dry soil.

RESULTS

In the field study, 40 plant species were investigated, some of which are medicinal plants such as: *Neurada procumbans, Zygopyllum qatarense*, *Heliotropium ramosissimum*. Other species belongs to pasture plants e.g. *Puncum turgedum*, *Alhagi maurorum, Poa annua.* On the other hand, the recorded plant species belong to different habitat classes namely: xerphytic, hydrophytic, halophytic and mesophytic habitat (Figures 2 to 6). With regards to life form; the studied plants can be grouped into geophytes: *Asphodelus hemicryptophyts*; phaneropytes: *Acaccia*; therophytes: *Chenopodium*, *Lotus lalambensis.*

Data in Table 1 indicates that soils supporting the growth of vegetation at study area are rich in calcium (68330 mg/kg) at site 8, sodium (49710 mg/kg) at site 2 and magnesium (8960 mg/kg) at site 8. Ammonia and chloride are commonly low in the studied area except site 3 where it reached 79682.33 ppm in surface soil layer.

The soil samples from sites 11 and 12 (Figure 1) have very low level of element contents. Some species are subjected to extensive decrease, over grazing and/or over collection (Table 2), namely: *Haloxylon salicornicum*, *Rhanterium epapposum*, *Seidlitzia rosmarinus*, *Panicum turgidum*, *Zygophylleum qatarence*, *Aleuropus lagopoides*, *Tamarix aphylla* and *Saueda aegyptiaca*.

Table 3 shows the plant diversity parameter of the studied area. Species richness index and Shannon-Weaver index values illustrate low diversity in the majority of the investigated sites of Dammam area. A total of 40 species representing 21 families are recorded. The family, Asteraceae and Chenopodiaceae are represented by the highest number of species (5 species) followed by, Poaceae and Zygophyllaceae (4 species), and Aizoaceae, Asphodelaceae, Fabaceae, Convolvulaceae and Polygonaceae (2 species), whereas other families such as, Brassicaceae, Cyperaceae, Geraniaceae, Juncaceae, Juncaceae, Lilliaceae, Malvaceae, Neuradaceae and Orobanchaceae are represented by a single species each (Figure 7).

Species diversity

The Shannon-Wiener's diversity index ranging from 2.815 to 0.588 are recorded for sites 6 and 7, respectively (Table 3). Relative abundance values for each site show that majority of the investigated species are within the rare category with one dominant species (Table 3). Figures 7 and 8 illustrate number of families and species in the study area.

DISCUSSION

Climate change is a crucial factor to consider when assessing the health of any species' population, but conservationists are left with the challenge of deciding exactly how to measure its potential impact on a given species (Still et al., 2015). It is worth mentioning that the vegetation is subjected to severe arid conditions, with prevalent climatic conditions in the area. Soil analysis (Table 1) illustrate wide diverse of chemical composition of soils supporting the growth of prevailing species of the study area.

Table 2 illustrates that the dominance and abundance of plant species varies widely. The existing species can be classified into different categories: Folk industries plants, medicinal plants, fodders/grazing plants and edible/food plants. Moreover, the results of species relations and soil factors revealed the fact that different species have reacted to soil differently.

The most conspicuous plant communities in this region are dominated by: *H. salicornicum*, *R. epapposum*, *P. turgidum*, *Calligonum comosum*, *Ephedra alata*, *Achillea fragrantissma– Artemisia siebri*, *Haloxylon persicum*, *Cornulaca arabica* and *Calligonum crinitum*, as well as

Table 1. Some chemical features of the soil supporting the growth of studied vegetation in different sites of Dammam area.

No	Depth (cm)	Sulfate (ppm)	Chloride (ppm)	Ammonia (ppm)	Magnesium (mg/kg)	Calcium (mg/kg)	Potassium (mg/kg)	Sodium (mg/kg)
1	0 - 5	160±8.0	123±10	10.15±0.5	3680±380	33470±3270	148.31±25.03	159.11±10.45
	5 - 30	25±6.0	19±2.0	7.35±1.35	2650±290	28190±4130	77.86±24.7	42.76±2.3
2	0 - 5	7111.5±296.5	79682.33±7432.5	5.6±1.5	8120±680	39140±4620	2919.08±356.74	49710±3410
	5 - 30	6963.5±869.5	5543±161	4.75±1.85	6900±620	39660±20	579.08±31.56	2860±40
3	0 - 5	479±65	392.73±83.25	3.95±0.55	4660±100	33840±860	172±22	172.48±80.12
	5 - 30	242±23	49.5±14.5	3.25±0.15	3680±200	30430±1810	102.46±19.78	58.8±9.42
4	0 - 5	674.5±78.5	119±18	11.25±3.95	5400±340	32860±1900	84.13±10.95	58.32±7.56
	5 - 30	74.5±23.5	82.25±3.25	3.35±0.25	3280±1060	28950±10670	161.98±25.98	84.95±30.95
5	0 - 5	2873.5±373.5	229.5±.50	5.65±0.95	5350±210	31340±1640	197.9±23.36	178.74±.74
	5 - 30	546±45	309±3	6.79±0.26	3920±40	32860±700	219.22±19.02	247.72±3.16
6	0 - 5	1538.1±234.7	4748.5±1767.5	8.4±1.3	6870±230	33140±1120	263.99±100.47	3072±748
	5 - 30	2060.5±147.5	182.5±58.5	6.15±0.95	5240±140	33070±2390	160.17±33.53	184.59±58.41
7	0 - 5	405±133	150.73±25.25	18.1±2.1	6530±570	41350±1550	305.31±51.97	101.78±0.38
	5 - 30	68±3.0	23±4.0	13.2±2.8	4500±480	35190±3790	242±49.26	73.36±9.66
8	0 - 5	700±7	169±1.0	7.7±1.1	8960±180	68330±450	517.05±27.91	153.6±26
	5 - 30	665.5±41.5	11.5±0.5	11.85±1.65	8360±380	63490±3890	507.57±57.67	144.7±7.7
9	0 - 5	131±7.0	129.5±5.5	25.1±8.1	3890±290	31980±1900	139.87±24.15	64.3±4.9
	5 - 30	66±4.0	31±0.0	15.25±4.75	1850±510	19740±6060	105.88±22.1	55.8±2.8
10	0 - 5	306±43	92±10	17.35±0.85	3700±20	36280±2320	189.54±5.43	143.1±6.1
	5 - 30	35.5±5.5	15.5±1.5	10.5±2.8	2840±660	32660±7500	152.11±60.29	60.86±43.71
11	0 - 5	41.36±2.76	155±119.45	2.44±0.48	11.13±2.3	85.2±6.53	6.13±0.15	2±0.0
	5 - 30	64.4±5.04	132.33±178.16	2.34±0.54	15.63±2.4	89.5±4.4	9.63±0.8	4±3.0
12	0 - 5	19.85±6.12	249±63	1.65±0.01	39.53±20.87	109.4±25.83	63.2±57.45	192±151.43
	5 - 30	48.2±11.93	76.66±21.5	1.49±0.19	11.9±3.45	62.86±32.61	15.2±2	42.66±17.21

the annual shrubless community of *Stipa capensis*, and some succulent halophyte communities (Migahid, 1996; Mandaville, 1990). The vegetation in the study area is the desert shrub rangelands type (Rahman et al., 2004).

A floristic analysis shows that majority of plants in the study area are annuals, while the minority group is in the tree (Figures 7 and 8). The dominance of members of Asteraceae and Chenopodiaceae, followed by Poaceae and Zygophyllaceae coincides with the findings of authors such as Turki and Al-Olayan (2003), El-Ghanim et al. (2010) and Alatar et al. (2012). On the other hand, the rainy season provides better chance for the appearance of a considerable number of annuals, which give a characteristic physiognomy to their vegetation (Shaltout and Mady, 1996; Hosni and Hegazy, 1996; Shaltout et al., 2010; Alatar et al., 2012). Moreover, the life form spectrum in eastern part of the study area reflects a typical desert flora, the majority of species being therophytes and chamaephytes. These results agree with the spectra of vegetation in desert habitats in other parts of Saudi Arabia This indicates that the dominance evenness of species generally tend to be within low values indicating low diversity.

Figure 2. *Erodium cicutarium* growing in Site 3.

Figure 3. *Cakile arabica* growing at Site 4.

Figure 4. *Caletropus procera* and *Zygophyllum coccinum* growing in Site 7.

Figure 5. Photo showing low diversity among site dominated with *Zygophyllum coccinum.*

Figure 6. *Convolvulus oxyphyllus,* one of endangered species collected from El Rayan district- Dammam City (Site 6).

Table 2. Endangered species recorded in the study area.

Species	Family	Phenology	Relative abundance index
Convolvulus oxyphyllus	Convulvulaceae	Veg./Fl.	Rare
Haloxylon salicornicum Rhanterium	Amaranthaceae	Veg./Fl.	Rare
epapposum	Composite	Veg./Fl.	Rare
Seidlitzia rosmarinus	Chenopodiaceae	Veg./Fl.	Rare
Panicum turgidum	Gramineae	Veg./Fl.	Rare
Zygophylleum qatarence	Zygo*phyllaceae*	Veg./Fr.	Rare
Aleuropus lagopoides	Gramineae	Veg./Fr.	Rare
Tamarix aphylla	Tamaricaceae	Veg.	Rare
Saueda aegyptiaca	Chenopodiaceae	Veg.	Rare
Avecinia marina	Aviciniaceae	Veg.	Frequent

Table 3. Relative abundance, species richness index D* and Shannon-Weaver index of plant species grown in the studied area at Dammam.

Site	Species	Family	Phenology	Density (No./m^2)	D*	Ra	H
1	*Launaea mucronata* (Forssk.) Muschl.	Asteraceae	Fl.	1	0.08±0.001	0.57% Rare	0.638±0.02
	Cakile arabica Velen.& Bornm.	Brassicaceae	Fr./Veg.	10		5.70% Rare	
	Kochia indica Wight.	Chenopodiaceae	Fr.	150		85.22% Dom	
	Heliotropium ramosissimum (Lehm.) DC.	Boraginaceae	Fr.	3		1.70% Rare	
	Malva parviflora L.	Malvaceae	Fr. Fl.	1		0.57% Rare	
	Poa annua L.	Poaceae	Fr.	3		1.70% Rare	
	(L.) Campd. *Emex spinosa*	Polygonaceae	Veg.	8		4.55 % Rare	
2	Bioss.& Sprum *Lotus halophilus*	Fabaceae	Fl.	3	0.72±0.02	4.34% Rare	1.232±0.11
	Erodium cicutarium (L.) L'Her.	Geraniaceae	Fr./Veg.	6		8.70% Rare	
	Malva parviflora L.	Malvaceae	Fr.	25		36.23% Freq.	
	annua L. *Poa*	Poaceae	Fr.	30		43.5% Abun.	
	Neurada procumbens L.	Neuradaceae	Fl./ Fr.	4		5.80% Rare	
	Senesio flavus (Decne) Sch. Bip	Asteraceae	Fr./Fl.	1		1.45% Rare	
3	*Chenopodium murale* L.	Chenopodiaceae	Fr./ Fl.	1	1.27±0.09	8% Rare	1.221±0.12
	Cakile arabica Velen.& Bornm.	Brassicaceae	Fr./Veg.	5		41 % Abun.	
	Asphodelus fistulosus L.	Asphodelaceae	Fr.	2		17 % Freq.	
	G. agea reticulata (Pall.)J.A.& J.H. Schultes	Lilliaceae	Veg.	2		17 % Freq.	
	Calotropis procera (Aiton) W.T.Aiton	Solanaceae	Veg.	2		17 % Freq.	
4	*Launaea mucronata* (Forssk.) Muschl	Asteraceae	Fl.	5	0.93±0.02	11.90% Freq.	1.380±0.13
	Heliotrpium digynum (Forssk) Ash.ex C. Christ.	Boraginaceae	Fr./Veg.	11		26.1% Freq.	
	Neurada procumbens L.	Neuradaceae	Fr.	20		47.62%Abun.	
	Lotus garcinii DC.	Fabaceae	Fr.	1		2.38% Rare	
	Poa annua L.	Poaceae	Fl./Fr.	2		4.76% Rare	
	Kochia indica Wight.	Chenopodiaceae	Fr.	3		7.14% Rare	
5	*Mesembeyianthemum nodiflorum* L.	Aizoaceae	Veg.	4	2.07±0.12	21.05% Freq.	2.412±0.21
	Aizoon hispanicum L.	Aizoaceae	Veg.	1		5.26% Freq.	
	Malva parfviflora L.	Malvaceae	Fr.	3		21.05% Freq.	
	Chenopodium album L.	Chenopodiaceae	Fr.	4		15.79% Freq.	
	Senesio flavus (Decne) Sch. Bip		Fl./Fr.	3		10.52% Freq.	
	Launaea capitata (Spreng.)	Asteraceae	Fr./Fl.	2		5.26%Rare	
	Fagonia indica Burm.f.	Asteraceae	Fr.	1		5.26% Rare	
	Cyperus conglomeratus Rottb.	Zygophyllaceae Cyperaceae	Veg.	3		10.52% Freq.	
	Asphodelus viscidulus Boiss.	Asphodelaceae	Veg.	2		5.26 % Rare	
6	*Convolvulus oxyphyllus* Boiss.subsp. *Oxycladus* Rech.f.	Convovulariaceae	Veg.	1	2.16±0.09	74.1% Rare	2.815±0.17
	Aizoon hispanicum L	Aizoaceae	Veg.	4		816.6% Freq.	
	Malva parfviflora L.	Malvaceae	Fr.	6		24.96% Freq.	
	Saueda aegyptiaca (Hasselq.) Zoh.	Chenopodiaceae	Fr.	3		12.48% Freq.	
	Seidlitzia rosmarinus Bunge ex Boiss.	Chenopodiaceae	Fl./Fr.	1		4.17 % Rare	
	Launaea capitata (Spreng.)	Asteraceae	Fr./Fl.	2		48.3% Rare	
	Fagonia indica Burm.f.	Zygophyllaceae	Fr.	3		12.48% Rare	
	Cyperus congrtulus	Cyperaceae	Veg.	2		48.3% Freq.	
	Asphodelus fistulosus L.	Asphodelaceae	Veg.	1		74.1% Rare	
	Aeluropus lagopoides (L.) Trin ex Thawaites	Poaceae	Fr.	1		4.17% Rare	

Table 3. Contd.

7	*Erodium cicutarium* (L.)L'Her.	Geraniaceae	Fr.	120	0.51±0.07	85.11% Dom	0.594±0.01
	Juncus rigidus Desf.	Juncaceae	Veg.	2		1.42% Rare	
	Salsola baryosma (Roem.et Schult.) Dandy	Chenopodiaceae	Fr.	4		2.84% Rare	
	Zygophyllum coccineum L.		Fr.	4		2.84% Rare	
	Malva parviflora L.	Zygophyllaceae Malvaceae	Fl./ Fr.	7		4.96% Rare	
	Panicum turgidum Forssk.	Poaceae	Fr./ Fl.	2		1.42% Rare	
8	Bioss.&Sprum *Lotus halophilus*		Fr.	4	1.24±0.21	12.5% Freq.	1.588±0.09
	Salsola imbricata Forssk.	Fabaceae Chenopodiaceae	Veg.	1		3.12% Rare	
	Zygophyllum coccineum L.	Zygophyllaceae	Fr.	4		12.5% Freq.	
	Poa annua L.	Poaceae	Fr.	4		12.5% Freq.	
	Panicum turgidum Forssk.	Poaceae Neuradaceae	Fl./Fr.	15		46.87% bun.	
	Neurada procumbens L.	Poaceae	Fr./Fl.	2		6.25% Rare	
	Lasiurus scindicus Henr.		Fl./Fr.	2		6.25% Rae	
9	*Phragmites australis* (Cav.) Trin.&Steudel.	Poaceae	Fr.	35	1.12±0.12	53.85%Abun.	1.397±0.17
	Mesemberianthemum nodiflorum L.	Aizoaceae	Veg.	3		4.62% Rare	
	Zygophyllum coccineum L.	Zygophyllaceae	Fr.	1		1.54% Rare	
	Juncus rigidus Desf.	Juncuaceae	Fr.	1		1.54% Rare	
	*Heliotrpium bacciferum*Forssk	Boraginaceae	Fl./Fr.	15		23.08%Freq.	
	Salsola baryosma (Roem.et Schult.) Dandy	Chenopodiaceae	Fr./Fl.	1		1.54% Rare	
	Cressa cretica L.	Convolvulaceae	Fr./ Fl.	6		9.24% Rare	
	Sonchus oleracus L.	Asteraceae	Fl./ Fr.	2		3.08% Rare	
	Neurada procumbens L.	Neuradaceae	Fr.	1		1.54% Rare	
10	*Fagonia indica* Burm.f.	Zygophyllaceae	Fr.	4	1.42±0.06	20% Freq.	1.675±0.21
	Cakile Arabica Velen.&Bornm.	Brassicaceae	Veg.	1		5% Rare	
	Sonchus oleraceus L.	Asteraceae	Fr.	5		25% Freq.	
	Malva parviflora L.	Malvaceae	Fr.	2		10% Freq.	
	Heliotrpium bacciferum Forssk.	Boraginaceae	Fr./ Fl.	2		10% Freq.	
	Senesio flavus (Decne) Sch. Bip.	Asteraceae	Fr./ Fl.	4		20% Freq.	
11	*Malva parviflora* L	Malvaceae	Fr.	5	0.780±0.01	30.33% Freq.	1.086±0.08
	Senecio glaucus L.	Asteraceae	Fr.	6		35% Abun.	
	Calotropis procera (Aiton) W.T.Aiton	Solanaceae	Veg .	2		11.2% Freq	
	Heliotrpium digynum (Forssk) Ash.ex C.Christ.	Boraginaceae	Fr.	4		22.67% Freq.	
12	*Fagonia schweinfurthii* (Hadidi) Hadidi	Zygophyllaceae	Fr.	2	1.74±0.01	6.06% Rare	2.047±0.12
	Tamarix nilotica (Ehrenb.) Bung	Tamaricaceae	Veg.	1		3.03% Rare	
	Calligonum comosum (L.)L'Her.	Polygonaceae	Fr.	3		9.09% Rare	
	Juncus rigidus Desf.	Juncaceae	Fr.	11		33.33% Freq.	
	Salsola kali L.	Chenopodiaceae	Fl./ Fr.	1		3.03% Rare	
	Phragmites australis (Cav.) Trin & Steudel.	Poaceae	Fr./Fl.	2		6.06%Rare	
	Cakile arabica Velen.&Bornm.	Brassicaceae	Fr./ Fl.	2		6.06% Rare	
	Zygophyllum qatarense Hadidi	Zygophyllaceae	Veg./Fl.	4		12.12%Freq.	
	Kochia indica Wight.	Chenopodiaceae	Fr.	4		12.12% Freq.	
	Cistanc hephelypaea(L.)Cout.	Orobanchaceae	Veg./Fl.	3		9.09 % Rare	

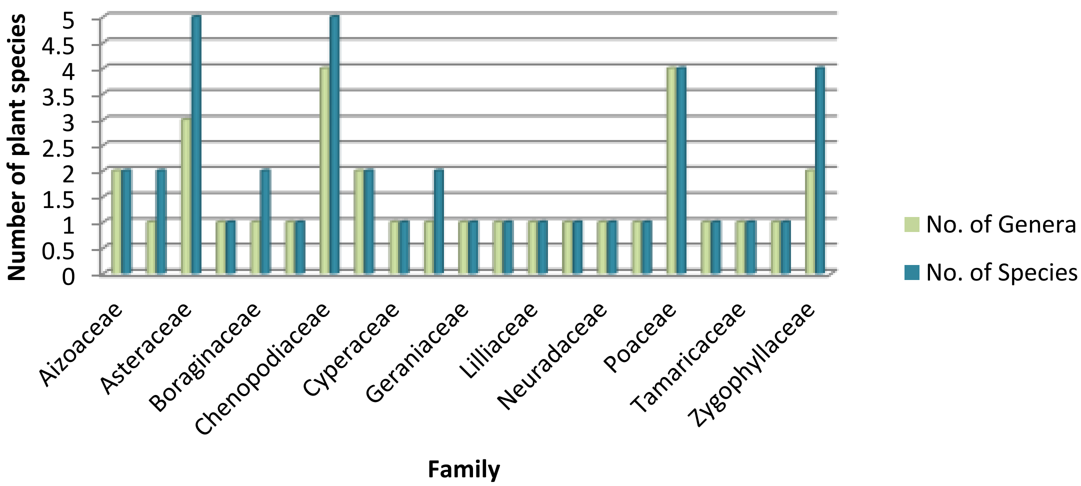

Figure 7. Number of families and species in the study area.

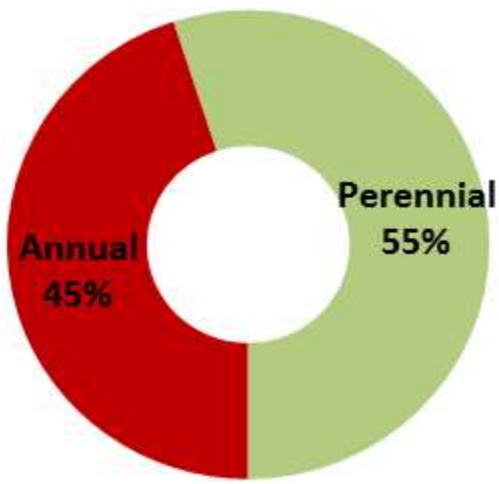

Figure 8. Growth of relative spectrum of the study area.

Degradation of the rangeland is evident in many parts of Saudi Arabia as a result of a long history of overgrazing (camels and sheep are the main grazing animals), overcutting, and many social, economic and cultural factors (Miller and Nyberg, 1991; Schultz and Whitney, 1986; Al-Rowaily et al., 2015). Protection against overexploitation provides a chance for regeneration of vegetation and for improvement of phytomass levels (Thomas et al., 2017). This is emphasized by many investigators (Gilbert, 2011; Pan et al., 2012; Chafjiri et al., 2016).

Generally, the plant diversity in the study area is extremely important from the environmental point of view as well as the economic importance. The environmental value is represented by: sand dune fixation, wind breaks, phytoremediation, atmospheric filtration and ecological balance, etc. (Meshal et al., 1985; Al-Taisan, 2009; Adler, 2011). Individual ecosystem functions generally show a positive asymptotic relationship with increasing biodiversity, suggesting that some species are redundant (Hector and Bagchi, 2007).

The diversity measurements (Table 3) illustrate low diversity of vegetation in the most studied sits. The plant diversity in Dammam sharply needs intensive conservation program, integrated studies and contentious monitoring. To overcome these hurdles, there is a need for coordinated efforts of scientists, government departments and nongovernmental organizations to undertake effective strategies for conservation of plants at Dammam area. This is emphasized by Shaltout et al. (1996). They found that 14 years of protection against grazing and human impacts of the coastal lowland vegetation in Eastern Saudi Arabia has led to an increase of 68% in the total cover, 33% in species richness and 32% in species relative evenness. Many of the species with significantly higher abundance in the protected area are important forage and/or fuel plants.

Conclusion

The study revealed that the high plant diversity and distribution of many plant species are deteriorated in Dammam due overgrazing and social behavior. Therefore, the plant diversity in Dammam sharply needs intensive conservation program, integrated studies and contentious monitoring. To overcome these hurdles, there is a need for coordinated efforts of scientists, government departments and non-governmental organizations to undertake effective strategies for conservation of plants at Dammam area.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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